Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 263 APRIL, 1957 No. 4

RADIATIONS AND THE GENETIC THREAT *

BY

WARREN WEAVER [1]

PRELIMINARIES

Explanations or apologies at the beginning of a speech are usually as uninteresting as they are artificial, but nevertheless I must make four preliminary remarks.

First, I am acting as an expositor and interpreter only. The topic before us involves deep aspects of the physical, the biological, and the medical sciences; and I certainly do not pretend to have technical competence in all these fields.

Second, just because so many fields of science are involved, and because various members of the audience are highly skilled in certain of these, I am condemned at the outset to bore some and confuse the rest. I will almost surely say too much for those who know, and too little for those who do not.

Third, the range and depth of subject matter is such that to cover the ground and to be reasonably intelligible one must simplify a good deal. Many of the following sentences should bear an asterisk, the footnote saying, "This statement isn't precisely correct. However, it is not misleading, and to make it exact would require a lot of pretty technical detail."

Fourth, I will not be concerned with all the effects of radiations on human beings, but primarily with the genetic aspects. This means that

* This is the 1956 Philip C. Staples Memorial Lecture, delivered at the Stated Meeting of The Franklin Institute, Wednesday, November 21, 1956. Spoken informally from brief notes, the Lecture has now been written out in very nearly its original oral form. The author hopes that it will thus gain in clarity, and perhaps even in interest, what it would lose if a more orthodox format tended to indicate that this is an academic problem rather than a very immediate one affecting every man, woman, and child.

[1] Vice President for the Natural and Medical Sciences, The Rockefeller Foundation, New York, N. Y.

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the direct effect of radiations on our own bodies will receive little if any attention.

THE PLOT

We all remember that Dickens used to start some of his novels with two or three chapters which appeared to be wholly unconnected. Then the relationship would gradually and dramatically come to light. Since our common purpose here is clarity rather than suspense, I will tell you at the outset that our plot will, in a way, be similar. Chapter I will be devoted to the villain of the piece—*radiations*. Chapter II will deal with the innocent victim—the *genes*. Chapter III will describe the crime—*mutations*. And Chapter IV will then give the verdict of society—will indicate, at least in modest part, *what we ought to do about this*.

THE VILLAIN—RADIATIONS

What is radiation? It is energy on the move—energy being transmitted from one location in space to another. But this remark requires an immediate modification. For not all energy on the move is radiation. A thrown baseball or the moving stream of water from a hose—these involve moving energy; but these are purely mechanical effects, rather than radiation. So we must be more accurate and say that radiation is *electromagnetic energy* being transmitted. I am not speaking here of electricity in wires, but rather of electromagnetic waves—radio or television waves—moving freely through space, or as we very inaccurately sometimes say "through the air." (This is really a bad phrase, for insofar as the air plays any role at all, it tends to stop such waves rather than transmit them. A century ago scientists used to say that these waves moved through the "aether," but they just invented this word to diminish their worry over the fact that they didn't understand what was happening. We don't either, but we have abandoned the verbal tranquilizer.)

The most familiar instance of an electromagnetic wave is *light*, the visible light which affects our eyes. And fortunately this familiar instance is a completely typical instance, as we will see in just a moment.

Any wave disturbance can be partly characterized by its *wave length*. In the case of a water wave, this wave length is simply the distance from one crest to the next adjacent crest. One can also speak of the *frequency* of a wave motion, this being simply the number of waves which in each second pass a fixed point. Granting a fixed speed for the waves (and this is the case with electromagnetic waves) the longer the wave length, the fewer of them pass a given point. Quantitatively, if you double the wave length, you halve the frequency. It is often useful to speak both of wave length, which is familiar to us from the water-wave case, and of frequency, which is familiar from the case of sound waves. When one

speaks of an "octave" on the piano, the frequency of the upper "do" is just twice the frequency of the lower "do"; so using the sound analogy one can speak of two electromagnetic radiations being an "octave" apart, one of them having a frequency twice that of the other.

In these terms (mixing the sound and light cases) we can think of a great "light-piano." Suppose its keyboard covers about seventy octaves. In the center of it, rather less than one octave wide, is the visible light that affects our eyes. To the right stretch out octave after octave of progressively higher frequencies (smaller and smaller wave lengths). First come about eleven octaves of so-called ultraviolet, the light that is bluer than blue. Then come four octaves of the still shorter wave length X-rays, six octaves of so-called gamma rays, and finally, shortest of all in wave length and highest of all in frequency, some sixteen octaves of very high energy gamma rays derived from cosmic rays.

To the left of the central octave of visible light we find about fifteen octaves of infrared light, then about six octaves of radar waves,[2] and finally some twelve octaves of ordinary radio waves.

That is to say, these physical entities with differing names—radio waves, infrared, visible light, ultraviolet light, X-rays, gamma rays, and cosmic rays—are now all known to be electromagnetic radiations which are alike except that they differ in wave length and hence in frequency. They range from the deep base of the radio waves at the left end of our radiation piano, up to the ultra high tenor of the cosmic rays at the right end. The only part of this whole spectrum of which we are immediately conscious is the less than one octave of visible light in the middle.

Speaking broadly, the very long wave length radiations tend to flow around any obstacle they meet, while the very short wave lengths tend to penetrate right into an obstacle. Since we are concerned here with radiations which are able to penetrate into our bodies, we see that we are dealing with the tenor half of the radiation piano, namely, with X-rays, the still more penetrating gamma rays, and the most of all penetrating cosmic rays.

At this point it will be useful to take note of the most common source of radiations. Most ordinary atoms are *stable*—their insides stay put. But some atoms are inherently *unstable*. Their insides have a tendency to readjust into a new pattern of arrangement. It is not possible to predict, for one particular atom, when this readjustment will occur. These unstable atoms—they are often called radioactive—are like alarm clocks wound up and set for unknown times. Eventually the alarm goes off, and the inside of that atom readjusts into a more stable arrangement. When that readjustment occurs, the atom sends out a burst of radiant energy, and this process is in fact the commonest origin of radiations.

[2] That is to say, waves of wave lengths which are very short when considered as radio waves, although not in the least short from the point of view of the entire electromagnetic spectrum.

Although one cannot at all say when one given radioactive atom will pop off, one can give a useful description of the time behavior of a lot of similar radioactive atoms. One does this by specifying the interval of time within which *half* of the atoms will pop off. This interval is called the *half-life*. Starting out with a large number of unpopped atoms of half-life equal to, just as an example, one day, half would be popped by the end of the first day, half of the remaining half of unpopped atoms would then pop in the second day (or a total of three fourths of the original number), again half of the remaining quarter of unpopped atoms in the third day (or a total of seven eighths of the original number, and so on. Some radioactive atoms have half-lives of minutes, hours, or days. There are some so transient that they have half-lives as short as a millionth of a second, and others so nearly stable that they have half-lives of thousands or even millions of years.

To return now to the general subject of this chapter, namely the radiations which are capable of penetrating our bodies, part are furnished by nature, and part are caused by man. The part furnished by nature is often referred to as the *background radiation*, this implying an inevitable and omnipresent base to which is added whatever man causes. Of this background radiation a certain amount comes *up* from the radioactive material in the rocks and soil. In the top layer of depth one foot there exists on the average, per square mile of earth surface, two grams of radium, eight tons of uranium, and twelve tons of thorium: so clearly the earth under our feet is an important and inescapable source of radiation. On the other hand, part of the background radiation comes *down* from the sky. This part is due to cosmic rays, so very penetrating that they can pass through ten centimeters of lead, and so universally present that as you read these lines some two to three hundred bursts are passing through your body each second. These two contributions, up from the soil and down from the sky, add together to form the background radiation.

In addition to this background that has been flooding man throughout the centuries are the radiations which man has recently learned how to produce. In this latter category there are two main kinds. First, there are the X-rays so widely used in medicine for both diagnostic and therapeutic purposes. Second, there are the rays (from our point of view the gamma rays are the important ones) produced in nuclear experiments, in atomic weapons testing, and in nuclear power plants. In addition to these two main kinds there are various other radiations, usually of minor importance or affecting fewer persons, such as are produced by luminous dials, encountered in certain industries, experienced by certain miners, etc.

The advent of atomic weapons has drawn attention to the possible dangers to man from all sorts of radiations. In the explosion of an atom bomb, in fact, there are produced about one hundred and seventy-five

kinds of what the physicist calls isotopes—abnormal variants of the ordinary elements. Some of these isotopes from an atom bomb are stable, and the unstable radioactive ones have half-lives which vary from a few seconds to a thousand million years. About one thousand pounds of radioactive material are produced per ten-megaton shot.

In the explosion of an atom bomb there are three discernible stages. The first, involving truly awful destruction from immediate radiation, heat, and blast, lasts for the order of one second and extends out, one supposes, to a ten- to twenty-five-mile radius. The second stage involves a radiation dose due to immediate fallout which is directly dangerous or even lethal to those receiving it. This lasts for a few days, and extends over an area which presumably may be ten thousand, or perhaps in special circumstances even one hundred thousand square miles. The third stage is that of the eventual "fallout." The finely dispersed radioactive material is carried high into the atmosphere, drifts with the winds, settles down at various rates, or is brought down with rain. This stage lasts over months or years, and extends over the entire planet. This third stage is what is usually meant by "fallout," and the word will be used here in this sense.

So now we have met the villain. It consists of blobs of penetrating energy produced by the popping off of wound-up atoms. Some of these atoms nature herself winds up, but many of these the modern physicist has learned how to wind.

THE INNOCENT VICTIM—THE GENES

Every cell of a person's body contains a great collection, passed down from the parents, the parents' parents, and so on back, of diverse hereditary units called *genes*. These genes singly and in combination control our inherited characteristics.

These genes exist in every cell of the body. But from the point of view of heredity the ordinary "body cells," which make up the body as a whole, are not comparably as important as the "germ cells" which exist in the reproductive organs, and which play the essential roles in the production of children.

Ordinarily a gene is passed on unchanged to children, grandchildren, and more remote descendants, but occasionally they do change. They are changed by certain agents, notably by heat, by some chemicals, and *by radiation*. It is at this point that we begin to see the villain plotting against the innocent victim.

THE CRIME—MUTATIONS

When a gene becomes thus permanently altered, we say it *mutates*. The gene is then duplicated in its altered form in each subsequent cell division. If the mutant gene is in an ordinary body cell it is merely passed along to other body cells. The mutant gene, under these cir-

cumstances, is not passed on to progeny, and the effect of the mutant gene is limited to the person in whom the mutation occurred.

However, it cannot safely be assumed that this body-cell effect is a negligible one on the person in whom the mutation occurred. For various kinds of cellular abnormalities are known to be perpetuated within an individual through body-cell divisions; so these effects are genetic in the broad sense. In fact, although the quantitative relations are not yet clear, it is nevertheless clear that certain malignancies such as leukemia, and certain other cellular abnormalities, can be induced by ionizing radiations. There is also some evidence that effects of this sort measurably reduce the life expectancy of the individual receiving the radiation.

But to return to a consideration of the risks which are passed on to progeny, the mutant gene may exist in a sperm or an egg cell as a result of a mutation having occurred either in that cell or at some earlier cell stage. In this case, a child resulting from this sperm or egg will inherit the mutant gene.

We are now in a position to indicate why it is that radiations, such as X-rays or gamma rays, can be so serious from the genetic point of view. For although the genes, as described above, normally remain unchanged as they multiply and are passed on from generation to generation, they do very rarely change, or *mutate;* and *radiation*, as we have already mentioned, *can give rise to such changes or mutations in the genes.* Mutation ordinarily affects each gene independently; and once changed, an altered gene then persists from generation to generation in its new or mutant form.

Moreover, the *mutant genes*, in the vast majority of cases, and in all the species so far studied, *lead to some kind of harmful effect.* In extreme cases the harmful effect is death itself, or loss of the ability to produce offspring, or some other serious abnormality. What in a way is of even greater ultimate importance, since they affect so many more persons, are those cases that involve much smaller handicaps, which might tend to shorten life, increase disease, reduce fertility, or be otherwise detrimental.

In assessing the harm done to a population by deleterious genes, it is clear that society would ordinarily consider the death of an early embryo to be of much less consequence than that of a child or young adult. Similarly a mutation that decreases the life expectancy by a few months is clearly less to be feared than one that in addition causes its bearer severe pain, unhappiness, or illness throughout his life. Perhaps most obviously tangible are the instances, even though they be relatively uncommon, in which a child is born with some tragic handicap of genetic origin.

A discussion of genetic damage necessarily involves, on the one hand, certain tangible and imminent dangers, certain tragedies which might occur to our own children or grandchildren; and on the other hand cer-

tain more remote trouble that may be experienced by very large numbers of persons in the far distant future.

This is not a suitable occasion on which to go into details. But due to well understood genetic principles, it is possible to state some important conclusions concerning the danger which is inherent in a radiation-mutated gene. First of all, the change produced by mutation is practically always a change for the worse. Second, the amount of mutation varies directly with the amount of radiation. Third, there is no minimum amount of radiation which is genetically safe—all radiation is genetically bad. A little radiation is a little bad, and a lot is a lot bad. Fourth, once exposed to some radiation, this never "wears off": that is to say, the genetically important number of mutations depends on the total dose that one accumulates from his own conception up to the time of conception of his last child. Fifth, the radiation that is important genetically is only that which reaches the gonads—that is to say, the male testicles and the female ovaries. Sixth, what counts from the point of view of society as a whole is the total number of mutated genes. Thus a small radiation dose to a large number of persons is, socio-genetically speaking, equivalent to a large dose to a few.

The resulting damage may, in a small proportion of cases, appear promptly in one's children or grandchildren: or it may be hidden for many generations: but it is usually not *completely* hidden, and almost always imposes some small handicap on all generations. Moreover these small handicaps accumulate, and the mutated gene eventually eliminates itself through disaster—the disaster of a person whose life span is so shortened or whose fertility is so impaired that no progeny is possible, and this particular genetic line dies out.

THE VERDICT OF SOCIETY

Crime, we ordinarily say, does not pay. One's natural inclination, knowing that any and all radiation is genetically bad, is to say, "Let's just eliminate radiation." But we couldn't do that if we really wanted to, and we wouldn't dare if we could.

We couldn't if we wanted to because of the background radiation which comes up from the soil and rocks, and down from the sky. This background is such as to give each person, on the average in the United States, a reproductive lifetime dose (say, over thirty years, from conception to the birth of the "average" child) of about 3 roentgens.[3]

[3] A *roentgen* is the common unit in which radiation dose is measured. You get a gonap dose of about 0.005 roentgen from a dental X-ray, from 0.1 to 1.0 roentgen from a pelvic X-ray, and up to 2 roentgens in a fluoroscopic examination of the pelvis. In the original report of the Genetics Committee of the National Academy of Sciences the background dose was estimated at 4.3 roentgens and the average dose from diagnostic and therapeutic medical X-rays was estimated at about 3 roentgens. A large amount of additional data has now been analyzed, and the result has been to decrease the estimate of the background dose to 3 roentgens, and to increase the estimate of the medical X-ray dose to about 4.5 roentgens. The estimate for the sum of the two thus remains nearly unchanged.

As a practical matter, moreover, it would be virtually impossible to eliminate man-made radiation also; but this is the part that we wouldn't really dare eliminate even if we could. To consider one type of man-made radiation, at the present time a person in the United States receives a reproductive lifetime dose of about 4.5 roentgens from diagnostic and therapeutic medical X-rays. Any of this that could be avoided without interfering with really necessary medical procedures should, of course, be eliminated. But obviously this involves careful and technical judgments in deciding, in each instance, which is the more acceptable risk—the genetic risk or the medical risk which would result in not using the X-rays.

In addition to the substantial doses from background and from medical X-rays there is the dose—up to the present time small—due to the radioactive fallout from atomic tests. And in the future we certainly face the possibility of significant doses from nuclear power installations.

The reproductive lifetime fallout dose has recently been estimated (assuming no increase in number or size of weapons tested) to be about 0.1 roentgen. There is a considerable uncertainty, and fluctuation from place to place, in this figure; and it may be a fifth as large as stated, or on the other hand, may perhaps be five times as large.

When we think of the genetic risk from any of these sources of radiation we should always, of course, think in terms of comparing two risks —the risk from the radiation, and the risk we would incur if we eliminated the radiation. We all have to compare risks every day, even though we usually do not do so explicitly, but rather in a vague and unformulated way which invokes experience.

If a person must go from New York to San Francisco, he could look up the traffic statistics, and could thus compare two actual numbers, representing the traffic deaths per mile of automobile or of air travel. But in the case before us there are reasons which make any attempted comparison of risk very difficult indeed.

We wish to compare Risk A, the genetic risk from radiation, with Risk B, the medical, economic, political, and military risk which might result from decreasing X-rays, from handicapping the development of nuclear power, and from weakening our position of world leadership and our capacity to defend ourselves. Our difficulties result from the very basic facts that we do not as yet know enough about human radiation genetics to give precise and quantatitive estimates of the radiation Risk A; that we certainly cannot give any accurate estimates of the medical, economic, political, or military Risk B; and that even if we could describe both Risk A and Risk B, there would be the final and baffling difficulty that these two risks are inherently unlike and hence essentially incomparable.

To speak only of Risk A, we must remember that our knowledge of

genetics is very largely derived from experiments with lower forms of life—fruit flies, corn, mice. Large-scale and controlled genetic experiments with human beings are obviously out of the question. Genetics, moreover, is an inherently complicated and subtle subject, almost no quantitative facts concerning radiation harm are known with high precision, and the great but necessary leap from mice to men is one which unavoidably introduces uncertainties. But do not make the mistake of concluding, from these discouraging comments, that the geneticists have little to offer in the way of knowledge and advice. On the contrary, and despite uncertainties about details and exact values, geneticists are in firm agreement on practically all of the really basic points.

Many of you will, at this point, want to make a protest, or will at least want to voice your confusion. If the basic genetic facts are indeed firm and agreed, how can different informed persons, all of whom are clearly intelligent and socially sensitive, appear to hold such diverse views? Take the much publicized case of fallout. How can some be worried about this as a serious menace, while others even refer to it as "harmless" or "negligible"?

The recent report of the National Academy of Sciences suggested that we ought to plan our medical and nuclear affairs so that an average U. S. citizen would receive a reproductive lifetime dose, from man-made radiation, of not more than 10 roentgens. Such an amount would probably not double our present genetic load, in the sense of doubling the long-established and long-tolerated rate of natural mutations from background radiation and from other agents (heat and chemicals) which cause radiations. Thus, the report concluded, perhaps 10 roentgens of man-made radiation will not result in an unreasonable burden to society. Well, if 10 roentgens thus gets enthroned as reasonable,[4] isn't the 0.1 roentgen from fallout negligible?

It is certainly not surprising that some persons, deeply and properly concerned over the military and political importance of nuclear weapons, answer that question in the affirmative. But the geneticists, if I interpret them correctly, answer in the negative. How can this be?

I think that this is to be explained, and that some of the differences in emphasis among the geneticists are also to be explained, in terms of two paradoxes—one numerical, the other temporal.

The numerical paradox is the one which applies most directly to the fallout problem. The paradox arises by virtue of the fact that some persons are impressed by relative figures, some by absolute amounts.

A fallout dose of 0.1 roentgen is, for example, only 1/100 of the 10 roentgens set as "reasonable" by the NAS report. It is only about 1/500 of the dose that would presumably be required to double the natural rate of mutation. If I am already running a certain risk (and after all

[4] *Reasonable*, mind you; not *harmless*.

surviving in spite of it) then ultimately to add to this risk by only one part in five hundred does, when put in this relative way, seem pretty negligible.

But look at the question in other terms. At the present time, roughly 4.5 per cent of the babies born in the United States have serious defects (congenital malformation, mental defectives, epilepsy, cutaneous and skeletal defects, visual and aural defects, etc.). Of these, it seems likely that about half are genetic in origin. Let us roughly assume that 2 per cent of the babies born have defects of mutational origin.

Now all the persons now alive in the world—all the persons who at this moment face this problem—will have, before they are all dead, something of the order of fifteen thousand million babies (1.5×10^9). The immediate genetic risk to this vast set of babies—the world's next set of persons—may well be increased, due to fallout, only by one part in 5000 (2×10^{-4}).[8] The increase in risk is very small; but the increase applies to a vast number of persons. The estimated result, in fact, is 6000 additional handicapped babies. Now what impresses you as more significant—that 6000 is a good many babies to subject to serious handicap, or that 1/5000 is a very small fraction and correspondingly is a very small relative addition to the thirty million babies that, without fallout, will have serious genetic handicaps? And remember that this calculation underestimates the total radiation effect in two ways: it speaks of first-generation damage (whereas there will be increasing amounts of damage in later generations), and it speaks only of gross abnormalities (which, if we accept the evidence from lower forms of life, constitute only a small part of the total genetic damage).

In connection with these remarks about the numerical paradox there is one aspect of the problem of genetic risk which probably deserves some explanation. Increasing some types of risk to individuals by one part in 5000 might just result in each individual person experiencing a small amount of additional harm—each one might, in an average year, say, have a certain type of physical distress for a total of five thousand and one minutes rather than for five thousand minutes, as previously. But genetic harm does not work that way. Mutations differ a great deal in their seriousness, of course. But for a given mutation, it either occurs or it does not occur. Thus when a lot of persons are subjected to a low radiation dose, almost all of them experience no harm whatsoever, but in the case of a few persons, mutation will occur. When a mutation occurs it occurs, so to speak, completely. The result for the person in whom it occurs is just the same as though the mutation had been caused by a larger dose of radiation. In other words, a small dose actually affects a small proportion of the exposed population, and a larger dose

[8] This factor is the product of 1/500 (a reasonable ratio of fallout to the doubling dose) by 1/10 (a reasonable estimate of the fraction of total damage which would be expressed in the first generation).

affects a larger proportion; but those individuals who are affected experience the same result in the two cases.

The temporal paradox is also a difficult one. What impresses you as more important—a relatively little tangible and tragic suffering encountered promptly, by your own children and grandchildren, say; or a great deal more of rather vague and remote suffering to be encountered by the next fifty or one hundred generations?

Some sincere and intelligent persons, including some geneticists, think it is difficult enough to try to play short-range God, without attempting, or worrying about, the problems of a long-range God. These persons, moreover, have a substantial comfort in their confidence that man's intellect will succeed in finding ways out of the long-range difficulties, so that we are justified in trying to deal only with the next few generations.

On the other hand, there are equally sincere and intelligent persons, again including some geneticists, who think that we may well have no greater responsibility than that of protecting the genetic heritage of the future; and that that responsibility does not in the least excuse our committing genetic crimes simply on the grounds that they will not be found out for a long time.

I hope that the statement of these two paradoxes may help you interpret certain statements which might otherwise confuse you, and—worst of all—might lead you to think that this situation is so mixed up that the best thing to do is disregard it. Whatever we do, we must not disregard this problem. A massive discontinuity was introduced into life by the discovery of nuclear fission. We have to learn to live with it, for the alternative is that we do not live.

Microscopes with "Push-Button" Illumination.—A new series of research microscopes with "push-button" illumination for faster and easier specimen analysis has been announced by the Bausch & Lomb Optical Co., Rochester, N. Y. The microscopes, known as the "R" series, incorporate many of the firm's standard Dynoptic research design features, with several major new developments in substage equipment.

Most important of these developments, according to the company, is an achromatic variable focus condenser which for the first time provides "push-button" illumination. The speed, accuracy and ease of the new illumination system's operation stem from the use of unusually large lenses in the condenser, a graduated numerical aperture scale, and a knurled ring for setting the lens system.

With the condenser in contact with a specimen slide, and with the correct illuminator, the field and numerical aperture of any objective from 30 mm. to 1.8 mm. can be filled. It also eliminates the need for auxiliary condensers to fill the field when a 30 mm., 3.5 × objective is used.

Conventional Abbe and Panfocal condensers are also available.

For photomicrography, measuring, microprojection and other special applications, a monocular body with a graduated draw tube can be substituted for the standard binocular body.

Other features include: eyepieces fitted with rubber inserts to protect the user's glasses; a control location which enables the operator to make adjustments without raising his hand from the table; concentric coarse and fine focusing knobs for the substage; a cast iron microscope arm for increased rigidity; and a graduated pupillary distance scale on the binocular eyepiece.

Automatic Reactor Shut-Down.—The "self-controlled" ability of an atomic energy research reactor to shut itself off if abnormal operating conditions occur has been demonstrated in tests conducted by Atomics International.

The tests have been made with a 50-kw. solution type, or "water boiler," research reactor specially constructed for the work at the company's Santa Susana Mountains field laboratory, about 30 miles northwest of Los Angeles. The program, called KEWB, for Kinetic Experiment for Water Boiler Reactors, is being conducted for the Atomic Energy Commission.

The object of the KEWB program is to study the detailed operating characteristics of the solution type reactor, one in which the nuclear fuel is contained in a water solution.

The studies include the demonstration of detailed physical qualities which cause the reactor to shut itself off if it is subjected to abnormal or unusual operating conditions. This automatic shut down characteristic, inherent in the solution type reactor, is due to temperature increases and formation of gas bubbles in the reactor fuel which results in the termination of the atomic fission process. Studies are also being conducted to determine the best reactor operating methods from the standpoint of general efficiency.

Atomics International, a division of North American Aviation, Inc., has built several solution type reactors now operating in the United States. Reactors of this type are now in construction by the company for installation in West Germany, Japan, and Denmark. The reactor type is particularly suitable for nuclear radiation studies and applications to the medical, industrial and research fields.

MULTIPLE SCABBING IN MATERIALS

BY

SUDHIR KUMAR [1] AND NORMAN DAVIDS [1]

ABSTRACT

This paper discusses first, scabbing and multiple scabbing from a phenomenological point of view, then past experiments on scabbing with critical comments. It then suggests new types of experiments and the use of an inverse approach which could yield information on pulse shapes and some of the dynamic properties of the material. The relationships among these quantities have been determined graphically.

1. SCABBING AND MULTIPLE SCABBING PHENOMENA

In recent years, effects due to rapid transients are becoming more and more important in the study of materials and the design of structures. "Scabbing" is an example of such an effect, which is produced, in a solid material, by a suddenly applied pressure of high intensity at its boundary, such as by an explosion. The name refers to the pieces of various shapes and sizes called "scabs" which tend to fracture from the specimen. Some simple examples of tests which lead to the formation of scabs are:

1. Explosion at one end of a rod (Fig. 1).
2. Fracturing in laboratory tension tests (Fig. 2). This effect occurs

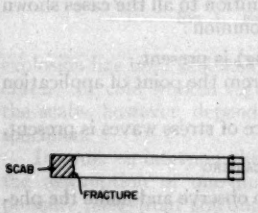


FIG. 1. Scab formation in a rod.

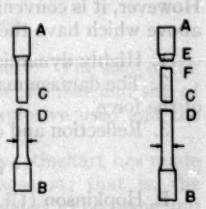


FIG. 2. Scabbing in tension specimens.

when a tension specimen is loaded rapidly in a testing machine, until fracture occurs (Fig. 2). A compression pulse then starts from the fractured end C which becomes reflected at A. This leads to another tensile fracture EF (Fig. 2). Thus either AE or FC can be considered as a scab.

3. Explosion on a flat plate. In this case, a scab usually in the shape of a segment cut from a sphere separates from the opposite side of the plate from which the explosion took place, as is shown in Fig. 3.

[1] Department of Engineering Mechanics, The Pennsylvania State University, University Park, Pa.

The above cases are among the more simplified of scabbing phenomena. In practice, if the explosion pulse is strong enough, the number of fracture surfaces may be quite large (up to five or more) as is also confirmed by experiments (Fig. 4). This is referred to as multiple scabbing.

An extreme example in which multiple scabbing plays a part is that of fragmentation or shattering. If a dynamic loading is intense enough, it creates a relatively small number of fractures initially which propagate by a chain reaction of fractures as a result of the reflected stress waves from the new fractured surfaces.

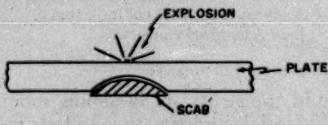


FIG. 3. Scabbing in a flat plate.

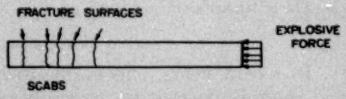


FIG. 4. Multiple scab formation.

In all these phenomena, there is a tendency for scabs of a definite and reproducible thickness to occur. In the case of fragmentation, although the actual size distribution of the particles is highly statistical, there is a tendency for the sizes of the fragments to occur near a certain mean size.

These experiments illustrate some of the varied aspects of scabbing. Originally, the name refers to the disk-shaped piece shown in Fig. 3. However, it is convenient to extend the definition to all the cases shown above which have the following effects in common:

1. Highly dynamic loading (or unloading) is present.
2. The damage may be located remote from the point of application of the force.
3. Reflection and destructive interference of stress waves is present.

2. PAST EXPERIMENTS ON SCABBING

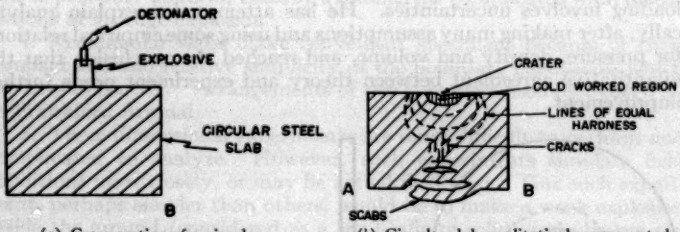
B. Hopkinson (1)[2] (1912) was the first to observe and name the phenomenon of scabbing in metal plates. He used steel plates of various thicknesses and detonated charges of gun cotton in contact with one of the surfaces of the plates. With thin plates (less than $\frac{1}{2}$ in. in thickness) Hopkinson found that a hole was punched through the plates. With plates of sufficient thickness, a circular disk of metal was fractured and then thrown off from the opposite face. This principle was used as a measuring device of pulses, in the well-known Hopkinson bar (2) which was perfected by R. M. Davies (3).

After Hopkinson's experiments, not much attention was paid to this phenomenon until recently when J. S. Rinehart (4, 5) and J. Pearson (6) performed a series of experiments in this country and Broberg (7)

[2] The boldface numbers in parentheses refer to the references appended to this paper.

in Sweden. Allen and Goldsmith (8) investigated the effect of the shape of the explosive charge on scabbing in plates. In England, some experiments involving scabbing on fracture of Perspex specimens by small explosions have been done by H. Kolsky (9, 10) and his colleagues. Some experiments of this kind have also been done in this country, such as by J. Feder at Frankford Arsenal and some others at Michelson Laboratory, Watertown Arsenal, etc. However, the quantitative studies made on scabbing experiments are very few, Rinehart and Broberg's experiments being the main amongst these. These two will be discussed here to some extent.

The general setup used by Rinehart for his experiments was as shown in Fig. 5*a*. In Fig. 5*b*, the general form of the specimen after



(*a*) Cross-section of a circular slab before explosion.

(*b*) Circular slab qualitatively represented after explosion at *P*.

FIG. 5. Experimental set-up for scabbing.

explosion has been sketched as observed by Rinehart. The sizes of the crater, the cold worked region, the cracks and the number and size of the scabs, however, depend on the amount of explosive used and the specimen.

In order to interpret the results quantitatively, Rinehart has made the assumption of one-dimensional pulse propagation; that is, the pressure pulse-front starting from *P* has been assumed to be plane and parallel to *AB* and also equally strong at every point of fracture. How-

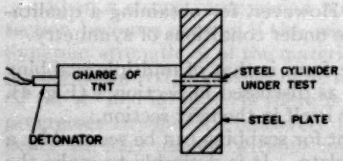


FIG. 6. Experimental arrangement for uniaxial strain.

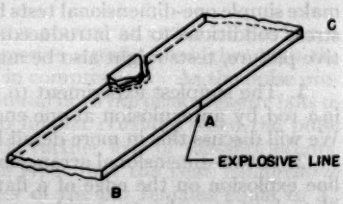


FIG. 7. Two-dimensional scabbing.

ever, even though as a first approximation, the above assumption may be accepted, it should not be forgotten that the pressure front has more of a spherical shape than plane and that its intensity is highest in a region directly below P in the plane AB. This approximation can be improved upon as suggested here further below.

Broberg did his scabbing experiments under conditions of uniaxial strains (see Fig. 6 for the setup used) instead of uniaxial stresses as chosen by other workers. This procedure has the advantage that a large and clearly recognizable number of scabs is produced. However, this leads to complications because of the fact that a triaxial stress condition is created by the explosive loads. The behavior of materials under dynamic triaxial stresses is very little known and as realized by Broberg himself, the estimation of fracture strengths at high rates of loading involves uncertainties. He has attempted to explain analytically, after making many assumptions and using some empirical relations for pressure, density and volume, and reached the conclusion that the quantitative agreement between theory and experiment needs further improvement.

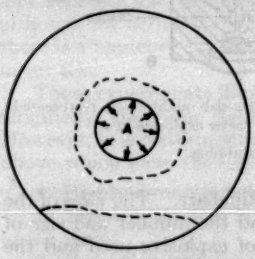


FIG. 8. Scabbing in a circular specimen.

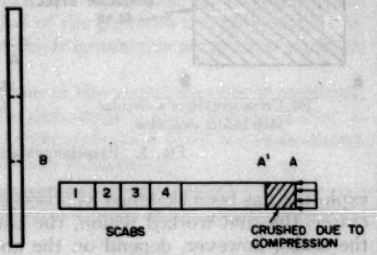


FIG. 9. Multiple scabs in a bar.

3. FURTHER POSSIBILITIES OF EXPERIMENTS ON SCABBING

To improve the state of knowledge we have on fractures of metals and other solids under very high rates of loading, it is desirable first to make simple one-dimensional tests before allowing complicated combined stress conditions to be introduced. However, for obtaining a qualitative picture, tests might also be made under conditions of symmetry.

1. The simplest experiment to perform is that of multiple scabbing in a rod by an explosion at one end, as discussed in Section 1 (Fig. 4). We will discuss this in more detail by itself in the next section.

2. A two-dimensional arrangement for scabbing can be secured by a line explosion on the edge of a flat plate. It is desirable to make the plate long in order to avoid complications arising due to end effects

(Fig. 7). The sizes of explosive charge and plate dimensions should be chosen such that the explosion at A is not strong enough to fracture the plate completely across the breadth, but strong enough to cause a scab. Plate BC should be taken quite long and can be supported at ends B and C but not below A, the point of explosion.

3. In Fig. 8 is shown a thin circular disk with a central hole A where the explosive is placed. If the explosion at A is too strong, radial cracks and fractures will take place without scabbing being observed. In order to avoid this, the inner hole should not be of a very small diameter. With proper adjustment of hole size and intensity of explosive, circumferential scabs and fractures should be observed. This test setup has an advantage over (2) in that the pressure distribution around the hole is probably uniform, thereby avoiding the complicated local distributions at an edge-explosion.

4. Rectangular slabs make convenient specimens because of their compact size and relative simplicity of the boundary conditions, which are easy to control. Arrangements of this type were used by Feder (11) at Frankford Arsenal.

5. Three-dimensional experiments are more difficult to perform and complicated to analyze. However, such experiments simulate field conditions most closely, or may be actual field tests. One such experiment, perhaps simpler than others, would be to make a weak explosion inside the ground (considered as a semi-infinite solid) and observe the scabs at the free surface. These would have the shape of shells and segments of spheres.

In all these experiments, the material should be one that is stronger in compression than in tension.

4. MULTIPLE SCABBING IN BARS

An experimental arrangement which generates multiple scabs may be used to yield information and data about pulse shape and dynamic fracture strength. Some aspects of this approach will be discussed below.

a. Governing Parameters

When a strong compression pulse is started at end A of the bar, a section becomes crushed if the compressive stresses are higher than the dynamic strength S_c of the material in compression. As the pulse progresses along AB, it crushes more material until the peak pressure falls to S_c (at A' in Fig. 9). As there is no further crushing when the pulse progresses beyond A', relatively little further loss of pressure occurs, hence we may assume without much error that the peak compressive stress in the pulse over the remainder of the bar remains equal to S_c. On reaching B, a reflected tensile pulse starts propagating in the reverse

direction, and when the resultant stress reaches the value S_T, the dynamic tensile strength of the material, one scab breaks off. If the pulse is sufficiently long, its tailing-end will now suffer reflection at this newly fractured surface—and, by the same process, will cause a second scab to fall off. This process continues until the reflected pulse becomes too weak to cause any further fracture; that is, whose maximum stress falls below S_T.

In short, the number and sizes of the scabs will depend greatly on

1. S_c, the dynamic strength of the material in compression,
2. S_c/S_T, the ratio of the dynamic strengths in compression and tension, and
3. shape of the pulse.

For the existence of scabs at all, it is of course necessary that the peak pressure in the incident pulse be greater than S_T, and that S_c/S_T should be larger than unity.

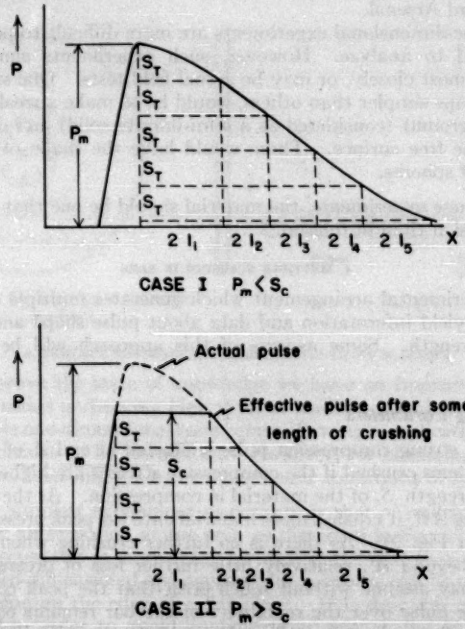


FIG. 10. Graphical construction of scab lengths from a given pulse.

b. Generalized Graphical Approach—Scab-Length Determination

It can be seen that the lengths of the scabs can approximately be determined by a simple graphical approach, if the shape of the pulse is known, as will be now explained.

Case I—Peak Pressure P_m Smaller than the Compressive Strength S_c

In this case, the pulse is not strong enough to crush any part of the rod and thus travels without much distortion. In order to determine the length of the various scales, we plot the given pressure pulse as pressure P *versus* distance x and mark off intercepts of length S_T starting from the top of the peak pressure P_m (Fig. 10). Differences of the abscissae of the various intercepted points give the length of the scab.

Case II—Peak Pressure P_m Larger than the Compressive Strength S_c

Here a part of the rod is crushed initially until the head of the pressure pulse is cut off (dotted part in Fig. 10). Thus, after crushing, the

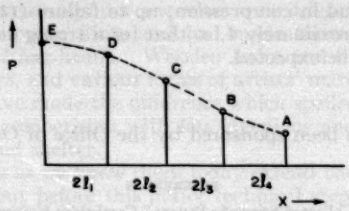


FIG. 11. Inverse construction for pulses.

actual pulse is reduced to the effective pulse and this propagates further in the rod and causes scabbing by reflections. Treating the effective pulse in the same way as above in Case I, the lengths of the scabs can be determined.

It may be noted that the above approach will hold good under the following conditions:

1. The peak pressure is reached almost suddenly.
2. After the peak, the pressure falls relatively slowly and monotonically.

The above two conditions are usually satisfied in the pressure pulse created by a single explosion and hence can safely be applied to the same.

5. INVERSE APPROACH—PULSE DETERMINATION

By generating scabs in a specimen of a suitable material, it should be possible to determine the shape of the pulse generated by an explosion. For example, if l_1, l_2, l_3 . . . etc. represent the various lengths of the first, second, third, . . . scabs, a number of points on the pulse-shape

curve is determined equal to the number of scabs. This is done by first plotting point A having the ordinate S_T, then plotting the next point B with ordinate $2S_T$, at a distance $2l_s$ to the left of A. The successive points C, D . . . are determined by marking off successively to the left $2l_1$, $2l_2$, . . . and erecting ordinates $3S_T$, . . . and so on. Passing a smooth curve through these points gives a set of points of the after-part of the pulse (Fig. 11). The steeply-rising part may be taken as vertical.

In regard to choice of material, the more scabs there are, the more points will be determined on the pulse curve. Hence

1. S_c/S_T should be as high as possible, and
2. since changes in the rate of propagation of plastic waves have not been considered, a material is desirable which has a stress-strain diagram as close to linearity as possible up to fracture.

It is not easy to find materials which satisfy this unusual combination of requirements. An example of one that does is Plaster of Paris. This material has a stress-strain relationship which is practically linear, both in tension and in compression, up to failure (12). Also, the ratio of S_c to S_T is approximately 4, so that for a strong enough pulse, about four scabs might be expected.

Acknowledgment

This work has been sponsored by the Office of Ordnance Research, U. S. Army.

REFERENCES

(1) B. HOPKINSON, "Collected Scientific Papers," Cambridge University Press, 1921.
(2) B. HOPKINSON, "A Method for Measuring the Pressure in the Detonation of High Explosives or by Impact of Bullets," *Phil. Trans.*, Vol. A 213, pp. 437–456 (1914).
(3) R. M. DAVIES, "A Critical Study of the Hopkinson Pressure Bar," *Ibid.*, Vol. A 240, pp. 375–457 (1948).
(4) J. S. RINEHART, "Some Quantitative Data Bearing on the Scabbing of Metals under Explosive Attack," *J. Appl. Phys.*, Vol. 22, pp. 555–560 (1951).
(5) J. S. RINEHART, "Some Experimental Indications of the Stresses Produced in a Body by an Exploding Charge," *Ibid.*, Vol. 22, pp. 1178–1181 (1951).
(6) J. S. RINEHART AND J. PEARSON, "Behavior of Metals under Impulsive Loads," Cleveland, Ohio, Am. Soc. Metals, 1954.
(7) K. B. BROBERG, "Studies on Scabbing of Solids Under Explosive Attack," *J. Appl. Mech., Trans. ASME*, Vol. 77, pp. 317–323 (1955).
(8) W. A. ALLEN AND W. GOLDSMITH, "Spall Effects by a Cylindrical and a Spherical Charge of High Explosive," *J. Appl. Phys.*, Vol. 25, pp. 813–814 (1954).
(9) H. KOLSKY AND D. G. CHRISTIE, "The Fractures Produced in Glass and Plastics by the Passage of Stress Waves," *Trans. Soc. Glass Tech.*, Vol. XXXVI, pp. 65–73 (1952).
(10) H. KOLSKY AND A. C. SHEARMAN, in *Research*, Vol. 2, p. 384 (1949).
(11) J. C. FEDER, R. A. GIBBONS, J. T. GILBERT AND E. L. OFFENBACHER, "The Study of the Propagation of Stress Waves by Photoelasticity," *Proc., Soc. Exptl. Stress Analysis*, Vol. XIV, pp. 109–118 (1956).
(12) G. MURPHY, "Properties of Engineering Materials," Scranton, Pa., International Textbook Company, 1947, p. 361.

THE ATOMIC NUCLEUS AND MODERN TECHNOLOGY *

BY

GAYLORD P. HARNWELL [1]

Technology is the corpus of those arts and crafts which have been devised by mankind for bending nature to his purposes. It comprises a large part of the "useful knowledge" which engaged the attention of Benjamin Franklin, which he established the American Philosophical Society to promote, and to the diffusion of which The Franklin Institute is devoted.

The history of technology is the story of man's increasing competence in meeting the challenges with which he has been faced from the days when he lived in caves, hunted with stone axes, and domesticated fire. This is a stirring tale of skill and ingenuity and perseverance, much of which extends far back beyond the dawn of recorded history. Thirty or forty thousand years ago our ancestors were adept at the highly demanding art of chipping flints and had made themselves serviceable knives, spears, and axe heads. Wooden hafts and handles, and bone skewers and needles, and various forms of artists' materials were in use. These may well have made the difference which spelled survival for our ancestors in their competition with less ingenious and adaptable competitors for food and shelter.

Written records as we know them today extend back only five or six thousands years, but before this major technical step which preserved the past and cemented primitive communities was taken, animals had been domesticated, the plow was in use, fields were irrigated and kings bearing metal weapons rode in wheeled chariots through archways. The ingenuity and resource which had earlier devised a multitude of tools and methods for hunting, fishing, and agriculture were turned to architecture, decoration, and recording. The congenial river valleys of the Near and Middle East saw smiths and lapidaries at work on the output of the mines and quarries of the northern mountains, weavers and potters plying their trades, artists of great talent decorating their handiwork, and the rudiments of quantitative thinking emerging in the centers of population.

The history of technology may be thought of in terms of three broad categories: power sources, materials, and devices and methods. The first millennium B.C. which witnessed the rise of western civilization and the birth of scientific thought was in possession of a technology which

* The Charles S. Redding Lecture, delivered at the Stated Meeting of the Institute held Wednesday, December 19, 1956, in the Lecture Hall.

[1] President, University of Pennsylvania, Philadelphia, Pa.

improved but little during the two subsequent millennia. The characteristics of the communities from India to Spain were determined by the technology at their disposal, and the meager changes that occurred in man's circumstances during the next two thousand years, say till the seventeenth century A.D., reflect a static technology.

The sources of power, were first of all, man himself and his draft animals—the horse, the ox, and the ass. These were supplemented to a small extent by water and air power for such things as milling and the propulsion of ships. The improvement of heat sources and the achievement of higher temperatures, for instance by the use of charcoal and bellows, enabled our early ancestors to extend the range of materials at their disposal. Porcelain and glass took their place beside the sun-dried bricks and the simple earthenware and pottery which had been known for many millennia. The successive ages of copper, bronze, and iron were doubtless determined by this increase in available temperature; for the order in which metals came into use is that of the electrochemical sequence which is the order of increasing heat of reaction with their oxides or sulfides. Gold is found uncombined; the heat of reaction of Ag_2O or Ag_2S is of the order of 5 kg.cal./mole. The figure for CuO is 35, for SnO_2 (for alloying with copper to form bronze) is 138; and for the iron oxides, Fe_2O_3 and Fe_3O_4, it is 190 and 265, respectively. It is upon these figures primarily that the difficulty of smelting depends. In a sense the history of mankind is the story of the technology of temperature and the later ages of steam, gas turbines, jets, and rockets have likewise been ushered in as a result of the attainment of ever higher temperatures and materials that permit their control and employment.

The devices that were made from the metals and ceramic materials at our ancestors' disposal and from their older animal, vegetable, and mineral resources, together with the methods whereby these devices were incorporated in their daily activities, again show little change from the age of Socrates to that of Newton. The arts of peace were particularly static, though changes in taste and refinement in artistry altered appearances and the rise in architectural skills permitted the enclosure of greater volumes with a considerable economy of material and convenience in construction and habitability. The arts of war, where greater competition spurred ingenuity, showed somewhat more advance in device and method from the siege of Troy to the fall of Constantinople. Armor, the war horse, and the long bow had little really new about them, but the invention or introduction of gunpowder about the middle of the fourteenth century was a major technological factor and revolutionized military methods after the middle of the sixteenth century; but here we are near the end of the two millennia of relative technological quiescence.

The past two centuries, and in particular the past fifty years, have seen greater technological advance than all of man's previous history.

In the main this is due to the progress of science and to the guidance which knowledge provides for man's ingenuity. The steam engine of Newcomen and Watt in the middle of the eighteenth century is the principal landmark in the development of power sources. But this had been supplemented importantly by the water turbine and the internal combustion engine, the gas turbine, and rocket motors. But most significantly the development of electromagnetic machinery from the pioneering research of Henry and Faraday has added flexibility to our power sources and permitted convenient and efficient distribution and application. The United States enjoyed a total electrical energy development last year of more than 3000 kilowatt hours per capita, and this is probably the greatest single factor in shaping the daily lives of Americans and differentiating them from their fellows who lived before the twentieth century.

The development of materials, the devices they provide, and the methods of their employment through which they serve our purposes cannot be summarized so simply. The development of the physical sciences in recognizing and isolating the chemical elements and investigating their relationships with one another in pure forms and under controlled conditions has been the major step in providing the materials at our disposal today. Again the advances in these sciences have provided the basis for the use of such materials in conjunction with the power sources and the electrical techniques of distribution and transformation. The variety and reliability of metals and their alloys is of a different order than it was fifty years ago; entirely new types of synthetic materials of every nature are now available. The quantity manufacture of chemicals of high purity forms an essential resource of industry; and pharmaceuticals and biologicals unknown to our fathers represent substances of the greatest significance for the biological sciences and for the improvement of our health.

The employment of these materials is an even more impressive story that cannot be summarized in a brief space. But as instances one need think only of the communication and transportation industries which link men together, the construction industries that bring into being our roads and dams, our great buildings and our small houses, the food processing industries, household appliance industries, and chemical and drug industries, all of which have transformed and ameliorated mankind's lot. These are indeed impressive triumphs of technology which are changing the face of the world and may well through their wider impact eventually assist in the rationalizing of man's relations with his fellows and contribute to both a better and more peaceful world.

Against this impressive background an entirely new and highly significant technology is developing from scientific investigations that date from the beginning of this century. Its contribution which is primarily to the categories of power sources and devices and methods has already

had an impact comparable to that of the main stream of molecular physics and chemistry which led to the age of steam and electricity. The glimmerings of these potentialities were first discernible in the work of Rutherford and his school in Cambridge. Working with the radioactive phenomena first observed by Becquerel and the Curies, Rutherford found that atomic nuclei were not as immutable as had been thought but that they could be altered under the influence of sufficiently violent impact with one another. These experiments, which were to change so profoundly the military thinking of a succeeding generation, were performed by a scientist who was not deflected from his calling by the alarums and dislocations of the first world war and who performed his crucial experiments in 1919.

At this point it is necessary to digress briefly into the salient points of the elementary concepts which are used to describe the structure of atoms, molecules, and atomic nuclei. The ninety-two different chemical elements of which our world is constructed are distinguished physically from one another by the elementary characteristics of the minute subdivisions or atoms of which they are composed. All atoms are found to be describable in terms of a minute massive core or nucleus which by reason of its positive electrical charge attracts to itself a number of light negatively charged particles called electrons, in sufficient number to be on the whole electrically neutral in their normal states. The atoms of the elements differ from one another in the mass of this central nucleus and in the magnitude of mass and charge run roughly parallel to one another through the sequence of the elements from the lightest, hydrogen, with one electron through helium with two, lithium with three and on up to uranium with the large number of ninety-two.

This ambient electron atmosphere or structure which surrounds the nucleus represents but a small percentage of the mass of an atom, but it determines almost exclusively its chemical properties. These electronic structures are minute. If a basketball were to be magnified to the size of the earth, the atoms of the gas which inflates it would resemble buckshot spaced on the average some few inches apart. When atoms combine together into molecules or condense into liquid or solid forms of matter the electronic structures surrounding the several nuclei may be thought of as coalescing their peripheries and maintaining a spacial relationship amongst the nuclei imbedded in this structure which is characteristic of the atoms forming the compound. The formation or rearrangement of compounds of atoms of this sort in which the electronic structures interact and interlock is known as a chemical reaction. The heat that is generated when a fuel burns represents the energy liberated during the comparatively minor readjustments in the electronic structures of all the participating atoms when they separate from their initial molecular combinations and reunite with the oxygen atoms which participate in the reaction. In the light of these considerations it is not

surprising that all fuels produce nearly the same amount of heat per unit of weight. The butterfat which is oxidized in our bodies, the charcoal that grills our steaks, and the gasoline which fuels our automobiles all produce about ten kilocalories per gram when they are burned. For this is derived from the rearrangement of electron systems, all of which are quite closely similar to one another.

The atomic nuclei which are so small on an atomic scale that they are separated by about a million times their diameters in molecular combinations are carried inertly through such chemical reactions retaining their charge and mass and individual identities without the least alteration. The first evidence that we could affect the nuclei themselves in any way came from the experiments of Rutherford in which he showed that the high speed helium nuclei emitted in radioactive processes would, on impinging on the nuclei of nitrogen atoms, bring about nuclear reactions in which fluorine nuclei were transiently formed which later emitted hydrogen nuclei and reverted to oxygen nuclei. ($He_2^4 + N_7^{14} \longrightarrow F_9^{18} \longrightarrow O_8^{17} + H_1^1$.) This was the small beginning of nuclear physics which through a few observations of individual nuclear events opened the possibility for the great developments of the past forty years.

The application of nuclear technologies as we know them today depends on a further circumstance; namely, that under certain conditions self-sustaining nuclear reactions analogous to the oxidation of chemical fuels can be brought about. The burning of carbon by oxygen depends both upon the liberation of energy during this reaction and on the fact that the energy thus liberated raises the temperature of the reactants to a point at which the reaction sustains itself. The possibility of any type of self-sustaining nuclear reaction depends upon the existence of types of reaction, called exothermic, in which energy on the whole is released and upon our ability to so dispose and control the reactants that the products and effects of the reaction promote its continuance rather than inhibit it.

The basic question of the availability of energy as a result of a nuclear reaction is answered by careful measurements of the masses of atomic nuclei and the Einstein relation between mass and energy. This relation states that energy is directly proportional to mass, the constant of proportionality being its square of the velocity of light: $E = mc^2$. From the work of Rutherford, Chadwick, and many others we find we can describe these minute nuclei as composed of combinations of two types of simpler and apparently elementary particles known as protons and neutrons. The proton is the nucleus of the lightest element, hydrogen, having a positive atomic unit of electric charge and the neutron is a particle of very nearly the same mass but with no electric charge at all. When these particles are assembled together the atoms of all the chemical elements can be constructed. The number of con-

stituent protons, Z, determines the number of charge units, and hence the external electron structure, and the number of neutrons in addition determines the total mass number, A. We find empirically that the number A for stable atomic species lies between $2Z$ and $3Z$. The measured masses of nuclei are not exactly Z times the proton mass and $(A - Z)$ times the neutron mass but somewhat less than this sum. The small discrepancy, which represents the loss of mass that comes from the association or binding together of these particles, is by the Einstein relation the binding energy analogous to the binding energy of chemical molecules.

However, the magnitudes of these nuclear binding energies are of the order of from one to ten million times as great as the molecular binding energies. If one looks at all of the atoms comprising the sequence of the elements, one finds that the atoms near the center of this group, in fact all the way from number 18, argon, to about number 36, krypton, have the largest energies of binding and hence are the stablest against decomposition, and that the lighter elements as well as the much heavier ones are less tightly bound nuclear aggregates. Thus, if reactions could be brought about which would either convert heavy elements into those near the center of the sequence by fission or which would combine lighter nuclei into heavier complexes by fusion, large amounts of energy would be released.

The first of these processes was observed with individual particles twenty years ago by Hahn and Meitner, and a technique was devised by Fermi and his colleagues at Chicago in 1942 for bringing about a controlled self-sustaining nuclear reaction of this sort. The reactor or furnace for employing nuclear fuel which was first used was a disposition of slugs of uranium metal and oxide in a lattice spacing throughout a cubic structure of graphite bricks approximately twenty feet on a side. A slowly rising temperature of the whole structure was the evidence that the reaction was taking place. This momentous achievement was the basis for the immediate military development of atomic bombs and for the present rising technology which promises to be as revolutionary in science and industry as it has been in war.

Not all heavy elements are suitable nuclear fuels in a fission process. The three elements that are known to undergo fission are two varieties of uranium, U_{233} and U_{235}, and also plutonium, Pt_{239}. The fission process is instigated by the absorption of a neutron incident on the nucleus, and the two major fragments into which the nucleus disintegrates are nuclei of elements of medium atomic weight. They separate with a kinetic energy equal to the shrinkage in mass which corresponds to about a hundred million (10^8) times the comparable chemical energy or heat of reaction. Smaller fragments, namely neutrons to the number of two or three, are also emitted at the fission process and the major atomic fragments are also not initially in their final state of aggregation but

emit delayed neutrons themselves as well as electrons and electromagnetic radiations as they settle down into their stable configurations. These neutrons both prompt and delayed are the ones which then continue the reaction through inducing successive fissions in other fuel nuclei. The initial neutron or neutrons may come from a cosmic ray process or from an artificial source brought into proximity with the reactor.

The details of this process are of intense interest and great practical importance. But the slowing down of neutrons by collision with the moderating material (such as the graphite or water surrounding the fuel), the conserving of neutrons for the process through the provision of reflecting materials (such as beryllium), the heavy shielding for protecting surrounding areas from the neutrons and radiation, the structural considerations, and the operating and controlling methods all lie beyond the subject at present under consideration. It is, however, important for our purposes to note that enough neutrons are not only emitted during fission of U_{235} to sustain the reaction but also to convert by absorption in the nuclei of the contiguous blanket of U_{238} or Th_{232} these nonfissionable materials into the fissionable fuels Pt_{239} and U_{233}, respectively. Thus, the potentialities of nuclear energy as a source of power are not limited to the naturally occurring U_{235} but may be greatly extended by the much vaster quantities of U_{238} and Th_{232} available.

Thus the first major contribution to the technology of the age of nuclear physics is the power reactor itself. Much of the basic research has been done, and the engineering development is well along in cooperation between private industry and government. About a score of stationary reactors for the generation of public service power are in contemplation or construction. Mobile units are in use in submarines to which they are ideally suited because atmosphere oxygen is not there available for the combustion of chemical fuels. Submarines have a number of very real advantages as vehicles for commerce or exploration which may bring them into future prominence as a result of matching an appropriate power plant to their other features. By proceeding well beneath the surface they don't produce surface waves, and not being retarded by this cause can show added speed or efficiency and for the same reason they provide a steadier platform and are not impeded by storms. The sea and its bottom may well hold great interest for us in the future, and the submarine is the most promising vehicle for exploration. In consequence the submarine may well be a major technological advance in the future of both science and commerce. Mobile nuclear power units are under consideration for displacement or surface vessels and these may be justified in special applications. Aircraft units are also under consideration but the technical problems of weights and temperatures are here very difficult; completely satisfactory solutions are questionable; and the advantages, if any, are marginal. There ap-

pears to be little to be gained by powering such land vehicles as busses, trucks, or locomotives with nuclear reactors.

Power from the nucleus for general consumption is the great civilian promise. The feasibility is no longer in question though operating techniques, economics, and safety are still very much under consideration. First of all, nuclear power must be recognized as simply nuclear fuel and not as replacing power plant machinery or electrical generation and distribution. All of the power system except the furnace or water wheel remains the same. The crux of the novelty is that the bulk of the nuclear fuel is less than a millionth the bulk of the equivalent chemical fuel; a cubic millimeter of U_{235} may be thought of as substituted for a cubic meter of fuel oil. Thus bulk fuel handling and transportation become of negligible concern, and the costs of operating power stations remote from coal mines can be greatly reduced. On the other hand nuclear fuel must be periodically purified of the products of nuclear disintegration (the medium weight elements formed) and this process is currently a highly technical and expensive operation though there are good prospects for technological advances and economies. The over-all economics are sufficiently promising to have enlisted private capital, and great progress can be expected with the actual operation of the pioneering installations. The health hazards are reasonably well understood and are being provided for very conservatively. The ultimate disposal of the disintegration products, many of which remain at dangerous levels of radioactivity for periods of years must be cared for, but with suitable precautions the depths of the sea or remote areas of the earth's surface may provide the answers.

If the nuclear age is simply offering us a new fuel, why do we make so much of a development which provides what we already have in abundance? The answer is two-fold, both domestic and foreign. In the first place, our supply of fossil fuel is far from unlimited. Lewis G. Weeks of the Standard Oil Company of New Jersey, who is one of the most knowledgeable persons in the field of petroleum geology, has estimated that the maximum of United States petroleum production is not more than ten years off and that in another ten years world production of petroleum will begin to decline. Natural gas, shale oil, and coal will extend our fuel supply, and to some extent alleviate the future fuel shortages, but this is a situation which is elastic to the extent of only a decade or two under the forces of supply and demand; and the end is in sight, if not imminent. Living, as opposed to fossil fuels are promising, as Farrington Daniels has shown, but they are not yet available. Nuclear fuels are assured for our domestic future and hence can provide a firmly established power source for the next generation if we make the necessary technical preparation now.

There are other countries in which fossil fuels are hard to come by today and where water power is not a promising alternative. These

extend from old established economies such as Great Britain to newer and undeveloped countries such as Australia. Without the helping hand of nuclear power, these people can see no way to compete in the next generation. It is not surprising that President Eisenhower's offer of twenty tons of our nuclear stockpile has been greeted with the greatest enthusiasm by every free nation in Asia and Africa; that Dag Hammarskjold foresees that world tension will be released through such a gesture; and even that an economic revolution will result in many areas through the use of nuclear fuels. The problems here are of a political rather than a scientific nature, but world concern with our policies in this field indicates clearly the magnitude and significance of the promise that may be realized as a result of nuclear power techniques.

The success of the initial developments in nuclear power leads naturally to two very deep and searching questions which represent probably the two greatest current challenges in this field. The first of these is: Why must we think of the nucleus, which in its disintegration emits many electrified particles, as a fuel or a heat source instead of through some ingenious arrangement as a direct generator of electricity? The rewards for the person who finds the answer, if one exists, to this question will be very great for it could bring with it great simplicity, economy, and efficiency but so far we have no lead at all as to how it can be accomplished, though much speculation and some systematic thought have gone into it.

The other question is: Since U_{235} is rare, U_{233} and Pt_{239} are synthetic, and the latter highly toxic, why do we not employ fusion reactions in which we combine hydrogen or lithium nuclei together into the less energetic complexes of medium weight atoms and make use of the energy so gained for our purposes? Again the rewards will be great if and when this is accomplished; but as yet we don't know how to do it. The Russian scientist, Kurchatov, told his British scientific colleagues at Harwell of some of the experiments his countrymen are performing with this end in view, and we are undoubtedly working on the problem on this side of the Atlantic, though as far as I know our program is classified. Nuclear physicists have accelerated hydrogen nuclei or protons to velocities sufficient to bring about a nuclear reaction with lithium as a result of which two helium nuclei are formed and an amount of energy equal to about a tenth of that liberated at a fission process is released. ($H_1^1 + Li_3^7 \longrightarrow Be_4^8 \longrightarrow 2He_2^4$.) The products are harmless and the reactants are relatively cheap and easily available, but the trouble is that we know of no way to make it self-sustaining. Reactions of this general type are major sources of energy of the sun and the other stars where the reactants are held together by gravitational forces in spite of the temperatures of several million degrees centigrade which are developed and which are necessary for maintaining the reaction, just as lesser temperatures of the order of a few hundred degrees

permit the maintenance of chemical combustion. But we know of no substances that will serve as nuclear furnace walls and will not vaporize at such nuclear reaction temperatures. The restraining effects of magnetic fields on charged particles or other possible expedients may eventually succeed in solving this problem but as yet we do not know how to employ nuclear fusion processes for the continuous and controllable provision of domestic power.

The military uses of atomic power, though a less welcome and congenial topic, are undoubtedly major components in our modern technology. Though specific information here is generally of a highly classified nature, the Atomic Energy Commission and its agencies have provided the general public with enough information to enable us to assess many of the technological consequences of this epoch-making development. The preceding considerations of nuclear reactions lay the ground work for understanding the major point of their military application. The energy available in comparable compass is a factor of a million or even a billion over that known for chemical explosives. Commissioner Libby tells us that the fission of a kilogram of uranium or plutonium is involved in a weapon equivalent to 20,000 tons of T.N.T. Known technology permits us to adapt this technique to smaller weapons of local tactical application fired from guns of regulation caliber, though at some decrease in the efficiency with which the fissionable material is used. Also fusion bombs have been constructed and tested in the range of millions of tons. These are awesome thoughts; and the possibilities of incorporating components that would enhance the after effects of radioactivity, leading to the rendering of great areas of the earth uninhabitable for long periods of time, is a further sobering deterrent to the resort to such terrific weapons of offense.

Chemical explosives differ from fuels in that they contain their own oxidant intimately incorporated with the fuel molecules, and hence as the reactants are in immediate spatial proximity high rates of reaction are possible. In the nuclear fusion bomb the reactant is simply the fissionable material, uranium or plutonium itself; and when this material exists in a magnitude and configuration such that neutrons, as promptly as they are generated, encounter and disrupt additional nuclei, the reaction proceeds with great rapidity and enormous amounts of energy are released in a small volume. It is this rapidity which renders the fusion bomb feasible. The inertial forces, which would have to be overcome to give the fusionable material and its binding and tamping, envelope an acceleration outward, retain the reacting material in close contact during the interval in which the rate of reaction and rocketing temperature amplify one another. Vast energies are released in this brief period before all the materials are vaporized and hurtle outward.

The effects of these weapons on military technology are probably greater than any other event in the long history of mankind. The

tactical employment represents only an extrapolation of the military thinking of measure and counter-measure and balance of offense and defense, but the strategic implications are of a different order and we are only beginning to appreciate what they may mean. Heretofore, an aggressor could anticipate that the victory for which he strives would confer such great relative advantage that his opponent would eventually become innocuous and his ability to retaliate would be crushed. Under these circumstances the stabilizing effects of morality, diplomacy, and the foreknowledge of the hazards of war have not been real deterrents and conflict has been the history of man's lot. Under present circumstances where it is beginning to be understood that no initial attack can be of such a magnitude as to prevent retaliatory devastation in kind, there is a new factor in the stabilization of international relations which, it may be fervently hoped, will prevent the outbreak of such world conflicts as we have witnessed twice in our generation.

The large scale employment of nuclear processes in bombs or power plants has raised a number of questions regarding the consequences of this new technology for our environment and for our lives. In the first place, it has been feared by some that there would be meteorological or climatological consequences which would alter our weather or otherwise affect the conduct of everyday affairs. There is no evidence for this possibility. Though the energies of nuclear fuels per unit volume or per unit mass are very large in comparison with those for molecular fuels, in the total rate of liberation of energy in man's or nature's processes or in the total quantity of energy released in such processes the proportion of the nuclear contribution is very small. The energy liberated in the condensation of water vapor in a moderate sized cloud, a few miles in its dimensions, which floats through the sky on a summer day is greater than that of a megaton bomb. And the energy of a very modest storm is much greater than all of the nuclear energy that has as yet been liberated. It is very unlikely that our efforts in nuclear technology could influence our climate appreciably, but it is not at all unlikely that the large output of carbon dioxide from the industrial and domestic consumption of molecular fuels will influence the delicate balance of the absorption of sunlight and re-emission of radiation by the earth and, in consequence, have an eventual secular influence on temperatures and the distribution of water in the form of ice, liquid, and vapor on the surface of the earth. Thus molecular fuel consumption is much more apt to have significant consequences on our environment than is that of nuclear fuel.

The health hazards, however, present a different picture, for the products of molecular fuel consumption are not significantly toxic. Here the comparison must be made with naturally occurring sources of radiation to which inhabitants of the earth have always been subject. The emanations from nuclear bombs, reactors, or the radioactive prod-

ucts of explosion or combustion which are often generically referred to as "radiation" consist of neutrons, electrons, a few fast massive atomic nuclei, and the short-wave electromagnetic radiations which are analogous to light but much more penetrating through ordinary matter. When such radiations pass through living tissue they disrupt the highly specialized molecular systems upon which the living processes depend; and while most organisms possess great recuperative powers, a dosage can be reached at which permanent damage results. We know far too little about these processes to reach the kind of assured conclusions we would wish; hence, great conservatism is appropriate and every effort should be bent to learn more in order that we may deal wisely and effectively with the problems presented. The types of gross effects that we observe to be caused by radiation are, first, the destruction of life processes; secondly, the disturbance of them with resulting abnormality; and, thirdly, the modification of genes with consequent hereditary influence. In general these are all detrimental, but we are inevitably exposed to such influences from our cosmic and geologic environment and always have been, so our concern must be for thresholds, relative enhancement, and novelties in magnitude and kind incident to the employment of nuclear reactions.

The unit in which the biological effects of radiation are measured is the "roentgen" which corresponds to the liberation of 100 ergs of energy in a gram of water or 10 joules per cubic meter (more strictly the definition of the "rud", a closely similar unit). The average dental X-ray examination delivers about 5 roentgens to the patient's jaw. Persons living at sea level receive from cosmic rays and natural radiation sources in the earth's crust of the order of 0.1 roentgen per year, but persons living on high plateaus in Tibet or the Andes may receive ten times this dose as would people flying in airplanes twenty or twenty-five thousand feet high. The dosage due to fallout of particles from atomic bomb tests sometimes reaches a rate of a few thousandths of a roentgen per year at distant points and falls to a fraction of this value in a week or so. A person during his lifetime may receive about 50 roentgens from natural causes; and the weapons tests, if continued at the rate of the past five years, would contribute only about one per cent above this background. So from this point of view the hazard seems small.

However, our ignorance of all matters related to the biological effects of radiations and the special circumstances we can envision should make us very cautious. A dose of 500 roentgens in a short period of time causes death in half the people so exposed, and much smaller doses even well separated in time can have serious effects. The problem of genetics is particularly difficult and subtle for we believe the effect of radiation on genes to be cumulative and that the doubling of the natural background would cause a rate of mutation which would eventually have serious genetic effects for the race, though to the best of my information

there is no factual information on high altitude communities that corroborates this conclusion. Nevertheless, great circumspection is clearly appropriate. The products of fission bombs or the fission products from nuclear fuel contain elements which the body can absorb and retain if these are present in our environment. High altitude bomb bursts that enter the stratosphere appear to contribute little fall-out that would be dangerous; but under certain meteorological conditions, low altitude bursts are hazardous over large areas, and a nuclear power plant accident could have very serious local consequences. Probably the most dangerous fission product is radioactive strontium-90 which, being chemically akin to calcium, is taken up by the body and incorporated in our bony structure. This has a half-life of the order of twenty-eight years, so almost all of it would be effective in the course of a long life. The Atomic Energy Commission is conducting extensive investigations in this field. Though there does not appear to be any immediate danger from strontium-90, the information that we may look forward to obtaining should enable us to understand the potential hazards and deal with them on a safe and conservative basis.

Our attention has been confined so far to atomic power as involving those nuclear technologies which have already had a major sociological effect. The measure of exploitation of nuclear technologies that we currently enjoy is but a decade old, and we are much too close to the birth of this new age and much too ignorant of the direction of its future evolution to make any judgment as to the ultimate promise extended to us by nuclear techniques. However, I am sure I am not alone in believing that what has been discussed above is mere prologue and that the greatest benefits are to come from the employment of nuclear phenomena in technology and research for the improvement of industrial processes and the advancement of our understanding of physical and biological phenomena. Though but the simplest beginning in this direction has as yet been made, even now in industry radioactive materials are being used to accomplish measurements which have previously been quite infeasible. Wear tests on tool bits, bearings, piston rings, and in rolling friction have added much to our control of industrial processes and to our basic knowledge of the properties of materials. Thickness testing, rates of fluid flow, nondestructive testing of materials, chemical analysis, the preserving of food, and the tracing of currents in the air and in the sea are all important functions which are now being performed routinely with the aid of nuclear technologies, though ten years ago, if not unthought of, certainly they were yet to be achieved.

Much greater promise, however, lies in the field of research and in the employment of nuclear technologies for investigating the basic properties of matter and the very challenging complex problems of living and growing systems. The physics of the elementary particles of which our universe is made is a region of investigation which not only generated

today's nuclear technology but which can best be advanced by employing this powerful tool to achieve an added measure of understanding of and control over our physical environment. Radioactive chemistry and radiation chemistry are in their infancies, and they promise not only improvements in present technology but the advent of entirely new possibilities. Finally, there is the peculiarly fascinating but intransigent area of the great molecular complexes, biological cells, and living systems where the techniques of radioactive tracers may provide the key for understanding elementary principles, visualizing the critical configurations which govern processes, and simplifying the vast body of qualitative and semi-quantitative observation to a point where our intellect can organize constructive hypotheses and theories. Science proceeds at a rate determined at least in part by the fund of knowledge at our disposal, and this is the exponential law that promises an increasing rate of progress and holds out the hope that every succeeding decade will provide greater rewards in knowledge and ability to apply it usefully in man's interest and to his greater well being. If nuclear technology is a component in justifying this expectation, our present triumphs are indeed but the dawn of a much brighter era.

ANALYSIS OF DIE PROFILES IN WIRE DRAWING

BY

L. W. HU [1]

SUMMARY

A method for the stress analysis of wire drawing using dies of any given profile is described. Examples of straight, concave, convex and bell-shape dies are investigated. Results indicate that the die profile has a significant effect on the distribution of die pressure and comparison shows that the bell-shape die has the lowest draw stress and the most uniformly distributed pressure and frictional force.

1. INTRODUCTION

The analysis of stress and strain in plastically deformed metals during forming processes has been of great interest to engineers for many years. In 1925 von Karman formulated the two-dimensional equations of equilibrium for strip-rolling of ideally plastic materials and a solution to the pressure distribution in a metal sheet during rolling was obtained (1).[2] Using the same approach as von Karman, Sachs analyzed the case of wire drawing (2). In 1944 Davis and Dokos reported their work on wire drawing taking into consideration the strain-hardening of metals (3). Many studies on the pressure distribution in wire drawing have been made since then. In recent years Hill and Tupper (4) and Shield (5) applied the concept of the slip line field to the analysis of wire drawing. In all cases, only a straight conical die was considered. However, it has been realized that the "draw" stress and die pressure in wire drawing is affected by the geometrical configuration of the die as well as by the amount of backpull, the strain-hardening of materials and the friction between wire and die. Considerable attention has been given to the control of die profiles for improving the efficiency of drawing tools and the quality of products (6, 7, 8). For instance, a bell-shape die is the outcome of an experimental study on die profiles conducted by Domes in 1951 (9).

In this paper, an analytical method to evaluate the effects of the die profile on the pressure distribution along the die in wire drawing will be developed. Thereby, the distribution of frictional force between wire and die for various die profiles can be determined. This knowledge will provide a means of comparing the quality of various die profiles and will enable a die to be designed with the profile best suited for the process.

[1] Department of Engineering Mechanics, The Pennsylvania State University, University Park, Pa.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

Nomenclature

The following notation is used in this paper:

r = radius of wire
r_1, r_2 = radius of wire at entry and at exit
x = axial position
σ_z, σ_r, σ_t = axial, radial and tangential stress
p = die normal pressure
μ = coefficient of friction
$\varphi(r)$ = profile function
$\bar{\sigma}$ = effective stress
$\bar{\epsilon}$ = effective strain
σ_0 = yield stress in simple tension
k = strain hardening coefficient
ϵ_z'', ϵ_r'', ϵ_t'' = axial, radial and tangential plastic strain
L = length of die
σ_d = draw stress
σ_b = backpull
$\beta = 1 - r/r_1$
$\lambda = (\beta_2 - \beta)^{\frac{1}{2}}$
$\gamma = (\beta_1 - \beta)^{\frac{1}{2}}$
F.F. = frictional force

2. GENERAL EQUATIONS

Consider that a metallic wire is forced through a cylindrical die as shown in Fig. 1 by applying a tensile force at the exit. By this process,

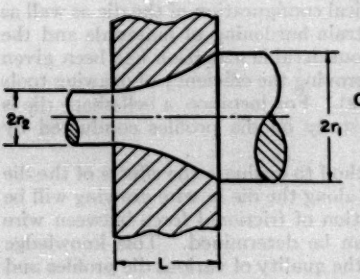


FIG. 1. Wire drawing.

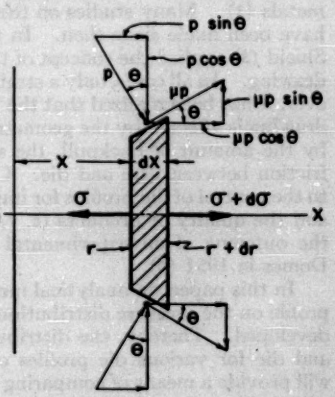


FIG. 2. Equilibrium diagram.

a circular cylindrical body of initial radius r_1 is transformed into another circular cylindrical body of smaller radius r_2. In a thin section of the wire of width dx and at distance x from the exit of the die, there are three

different horizontal forces acting on this element. As shown in Fig. 2, one is the horizontal component of the pressure between wire and die, or $2\pi rp \tan\theta\, dx$; a second is the horizontal component of the frictional force, or $2\pi\mu rp dx$; and a third is the force due to the axial stresses σ_x. If the stress σ_x is assumed to be uniformly distributed, this third force has a value

$$\pi(r + dr)^2(\sigma_x + d\sigma_x) - \pi r^2\sigma_x \doteq 2\pi r\sigma_x dr + \pi r^2 d\sigma_x.$$

Neglecting the inertia forces, the equation of equilibrium for the element becomes

$$2\sigma_x dr + r d\sigma_x + 2p(\tan\theta + \mu)dx = 0. \tag{1}$$

If the profile of the die can be expressed as $x = \varphi(r)$, then

$$\left.\begin{aligned} dx &= \varphi'(r)dr \\ \tan\theta &= \frac{1}{\varphi'} \end{aligned}\right\}. \tag{2}$$

Substituting the values of dx and $\tan\theta$ from Eq. 2 into Eq. 1,

$$r\frac{d\sigma_x}{dr} + 2\sigma_x + 2p(1 + \mu\varphi') = 0. \tag{3}$$

In deriving Eq. 3, the shearing stresses are considered negligible, and a plane section is assumed to remain plane during wire drawing. Accordingly the radial and tangential stresses are found to be

$$\sigma_r = \sigma_t = -p(1 - \mu\tan\theta) = -p\left(1 - \frac{\mu}{\varphi'}\right). \tag{4}$$

The effective stress $\bar{\sigma}$ defining plastic flow can be expressed as

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[(\sigma_x - \sigma_r)^2 + (\sigma_r - \sigma_t)^2 + (\sigma_t - \sigma_x)^2\right]^{\frac{1}{2}}$$

$$= \sigma_x + p\left(1 - \frac{\mu}{\varphi'}\right). \tag{5}$$

Solving for p from Eq. 5 and placing the value of p into Eq. 3,

$$r(\mu - \varphi')\frac{d\sigma_x}{dr} + 2\mu(1 + \varphi'^2)\sigma_x = 2\varphi'(1 + \mu\varphi')\bar{\sigma}. \tag{6}$$

By considering the fact that the radial and tangential stress components are equal, the combined stress state in the stressed portion of the wire

can be considered as a simple tension with superimposed hydrostatic pressure. In this way the concept of total plastic deformation can be used in the analysis of wire drawing. For this purpose, an effective strain $\bar{\epsilon}$ is defined by

$$\bar{\epsilon} = \frac{\sqrt{2}}{3}[(\epsilon_z'' - \epsilon_r'')^2 + (\epsilon_r'' - \epsilon_t'')^2 + (\epsilon_t'' - \epsilon_z'')^2]^{\frac{1}{2}}. \tag{7}$$

For many engineering materials, it has been found (10) that the plastic stress-strain relation can be expressed as

$$\bar{\sigma} = \sigma_0 + k\bar{\epsilon}. \tag{8}$$

In formulating Eq. 8, the material is assumed to be plastic rigid material. This is justified since the deformations dealt with in metal forming are

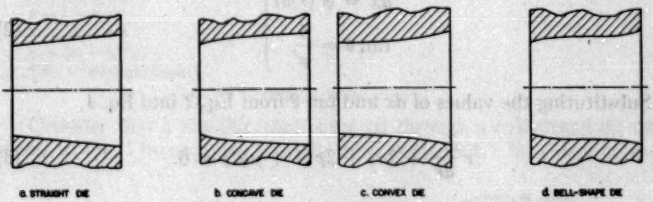


FIG. 3. Die profiles.

large and the elastic strain components can be considered negligible. The tangential and radial strains can be shown to be

$$\epsilon_r'' = \epsilon_t'' = \ln\left(\frac{r}{r_1}\right). \tag{9}$$

Taking into consideration that the volume remains constant during plastic deformation and using Eqs. 7 and 9, Eq. 8 becomes

$$\bar{\sigma} = \sigma_0 - 2k \ln\left(\frac{r}{r_1}\right). \tag{10}$$

Placing the value of the effective stress $\bar{\sigma}$ into Eq. 6

$$r(\mu - \varphi')\frac{d}{dr}\left(\frac{\sigma_z}{\sigma_0}\right) + 2\mu(1 + \varphi'^2)\left(\frac{\sigma_z}{\sigma_0}\right) = 2\varphi'(1 + \mu\varphi')\left[1 - 2\left(\frac{k}{\sigma_0}\right)\ln\left(\frac{r}{r_1}\right)\right]. \tag{11}$$

If the coefficient of friction μ between wire and die is known and the die profile as defined by $x = \varphi(r)$ is given, the variation of axial stress in the wire is completely defined by Eq. 11. The pressure distribution in the die can then be determined by combining Eqs. 5 and 11.

In order to show the effects of die profile on the pressure distribution and draw stress in wire drawing, a straight die and dies of three other given profiles will be analyzed by using Eq. 11.

3. STRESS RELATIONS FOR STRAIGHT DIE

Consider a straight conical die as shown in Fig. 3*a* with a profile which can be expressed analytically as

$$x = L\left(\frac{r - r_2}{r_1 - r_2}\right). \tag{12}$$

Defining

$$\alpha = \varphi' = \frac{1}{\tan\theta} = \frac{L}{r_1 - r_2} \tag{13}$$

and placing the value of φ' from Eq. 13 into Eq. 11, results in

$$r(\mu - \alpha)\frac{d}{dr}\left(\frac{\sigma_x}{\sigma_0}\right) + 2\mu(1 + \alpha^2)\left(\frac{\sigma_x}{\sigma_0}\right) = 2\alpha(1 + \mu\alpha)\left[1 - 2\left(\frac{k}{\sigma_0}\right)\ln\left(\frac{r}{r_1}\right)\right]. \tag{14}$$

It can be shown that the solution of the first order differential equation (14) is

$$\frac{\sigma_x}{\sigma_0} = \left(\frac{\sigma_b}{\sigma_0}\right)\left(\frac{r}{r_1}\right)^{-A} + \left(\frac{B}{A}\right)\left[1 + 2\left(\frac{k}{\sigma_0}\right)\frac{1}{A}\right] \times \left[1 - \left(\frac{r}{r_1}\right)^{-A}\right] - 2\left(\frac{B}{A}\right)\left(\frac{k}{\sigma_0}\right)\ln\left(\frac{r}{r_1}\right), \tag{15}$$

where

$$A = \frac{2\mu(1 + \alpha^2)}{\mu - \alpha}$$

$$B = \frac{2\alpha(1 + \mu\alpha)}{\mu - \alpha}.$$

In obtaining Eq. 15, the boundary condition at the entry was used, namely that the axial stress σ_x in the wire is equal to the backpull σ_b.

The axial stress σ_x at the exit where $r = r_2$ is the draw stress σ_d needed to accomplish the process and is found from Eq. 15 to be

$$\left(\frac{\sigma_d}{\sigma_0}\right) = \left(\frac{\sigma_b}{\sigma_0}\right)\left(\frac{r_2}{r_1}\right)^{-A} + \left(\frac{B}{A}\right)\left[1 + 2\left(\frac{k}{\sigma_0}\right)\frac{1}{A}\right] \times \left[1 - \left(\frac{r_2}{r_1}\right)^{-A}\right] - 2\left(\frac{B}{A}\right)\left(\frac{k}{\sigma_0}\right)\ln\left(\frac{r_2}{r_1}\right). \quad (16)$$

In the case of ideally plastic material, the stress distribution as defined by Eq. 15 will be reduced to the results obtained by Sachs (2) by letting $k = 0$.

4. STRESS RELATIONS FOR CONCAVE DIE

Consider the case of a conical die with a concave profile as shown in Fig. 3*b*. If the die profile is given as

$$x = L\left(\frac{r - r_2}{r_1 - r_2}\right)^2 \quad (17)$$

then

$$\varphi' = \frac{dx}{dr} = \frac{2L(r - r_2)}{(r_1 - r_2)^2} = G(r - r_2). \quad (18)$$

Defining β as $\beta = 1 - \frac{r}{r_1}$, so that $r = (1 - \beta)r_1$, then φ' in Eq. 18 becomes

$$\varphi' = Gr_1(\beta_2 - \beta), \quad (19)$$

where $\beta_2 = 1 - \frac{r_2^2}{r_1}$. Placing the value of φ' from Eq. 19 into Eq. 11 and changing the variables,

$$\left[\left(\beta_2 - \frac{\mu}{Gr_1}\right) - \left(1 + \beta_2 - \frac{\mu}{Gr_1}\right)\beta + \beta^2\right]\frac{d}{d\beta}\left(\frac{\sigma_z}{\sigma_0}\right) + 2\frac{\mu}{Gr_1} \times [(1 + G^2r_1^2\beta_2^2) - 2G^2r_1^2\beta_2\beta + G^2r_1^2\beta^2]\left(\frac{\sigma_z}{\sigma_0}\right) = 2[(1 + \mu Gr_1\beta_2)\beta_2 - (1 + 2\mu Gr_1\beta_2)\beta + \mu Gr_1\beta^2]\left[1 - 2\frac{k}{\sigma_0}\ln(1 - \beta)\right] \quad (20)$$

in which $\ln(1 - \beta)$ can be expanded into a power series of β. It can be shown that the solution of Eq. 20 can be expressed as the power series

$$\left(\frac{\sigma_z}{\sigma_0}\right) = \sum_{i=0,1,2\ldots} A_i\beta^i, \quad (21)$$

where the coefficients A can be determined from the following recurrence formula

$$n\left(\beta_2 - \frac{\mu}{Gr_1}\right)A_n + \left[\frac{2\mu}{Gr_1}(1 + G^2r_1^2\beta_2^2) - (n-1) \times \left(1 + \beta_2 - \frac{\mu}{Gr_1}\right)\right]A_{n-1} + [(n-2) - 4\mu Gr_1\beta_2]A_{n-2} + 2\mu Gr_1A_{n-3} - B_{n-1} = 0, \quad (22)$$

where

$$B_0 = 2(1 + \mu Gr_1\beta_2)\beta_2$$

$$B_1 = -2(1 + 2\mu Gr_1\beta_2) + 4\left(\frac{k}{\sigma_0}\right)(1 + \mu Gr_1\beta_2)\beta_2$$

$$B_2 = 2\mu Gr_1 + 2\left(\frac{k}{\sigma_0}\right)[-2 + (1 - 4\mu Gr_1)\beta_2 + \mu Gr_1\beta_2^2]$$

$$B_m = 4\left(\frac{k}{\sigma_0}\right)\left[\frac{(1 + \mu Gr_1\beta_2)\beta_2}{m} - \frac{(1 + 2\mu Gr_1\beta_2)}{m-1} + \frac{\mu Gr_1}{m-2}\right]$$

for $m = 3,4,\ldots$.

In Eq. 22 the index n is a non-negative integer. In case the A's have negative subscripts they are considered to be equal to zero. By considering the boundary condition at the entry where $\beta = 0$ and the axial stress σ_x is equal to the backpull σ_b, it is found that $A_0 = \frac{\sigma_b}{\sigma_0}$. Substituting the value of A_0 and the known values of μ, a, r_1, k and σ_0 into Eq. 22, all the coefficients in the series solution Eq. 21 can be determined.[3] In practice, the ratio of the final radius r_2 of the wire to its initial radius r_1 is usually greater than 0.4. Therefore, in the series solution given in Eq. 21, only the first few terms are essential. The degree of the accuracy of the solution, however, will be governed by the number of terms considered.

5. STRESS RELATIONS FOR CONVEX DIE

Let us consider the case of a conical die with convex profile as shown in Fig. 3*c*. If the die profile is given as

$$x = L\left(\frac{r - r_2}{r_1 - r_2}\right)^{\frac{1}{2}} = \frac{L}{\sqrt{\beta_2}}(\beta_2 - \beta)^{\frac{1}{2}} \quad (23)$$

then

$$\varphi' = \frac{dx}{dr} = \frac{L}{2r_1\sqrt{\beta_2}}(\beta_2 - \beta)^{-\frac{1}{2}} = \frac{H}{\lambda}, \quad (24)$$

where

$$H = \frac{L}{2r_1\sqrt{\beta_2}} \quad \text{and} \quad \lambda = (\beta_2 - \beta)^{\frac{1}{2}}.$$

[3] The power series Eq. 21 determined in this manner is convergent if the values of (r_1/L), μ and β_2 do not make the ratio $|A_{n+1}/A_n|$ equal to or greater than $(1/\beta_2)$.

Using a procedure similar to that used in the previous sections, that is, placing the value of φ' from Eq. 24 into Eq. 11 and changing variables, the differential equation of equilibrium becomes

$$\tfrac{1}{2}[-H(1-\beta_2)+\mu(1-\beta_2)\lambda-H\lambda^2+\mu\lambda^3]\frac{d}{d\lambda}\left(\frac{\sigma_z}{\sigma_0}\right)+2\mu(H^2+\lambda^2)\times\left(\frac{\sigma_z}{\sigma_0}\right)=2H(\mu H+\lambda)\left[1-2\left(\frac{k}{\sigma_0}\right)\ln(1-\beta)\right] \quad (25)$$

in which $\ln(1-\beta)$ can be expanded into a power series in β, and then transformed into a series in λ. It can be shown that the solution of Eq. 25 can be expressed as a power series

$$\left(\frac{\sigma_z}{\sigma_0}\right)=\sum_{i=0,1,2\ldots}C_i\lambda^i, \quad (26)$$

where the coefficients C can be determined from the following recurrence formula

$$\tfrac{1}{2}\{n(1-\beta_2)HC_n-\mu[(n-1)(1-\beta_2)+4H^2]C_{n-1}+(n-2)HC_{n-2}-(n+1)\mu C_{n-3}\}+D_{n-1}=0, \quad (27)$$

where

$$D_0=2\mu H^2\left[1+2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{\beta_2^{m+1}}{m+1}\right]$$

$$D_1=2H\left[1+2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{\beta_2^{m+1}}{m+1}\right]$$

$$D_2=-4\mu H^2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\beta_2^m$$

$$D_3=-4H\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\beta_2^m$$

$$D_4=2\mu H^2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}(m+1)\beta_2^m$$

$$D_5=2H\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}(m+1)\beta_2^m$$

$$D_6=-\frac{4}{3}\mu H^2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{(m+1)(m+2)}{2}\beta_2^m$$

$$D_7=-\frac{4}{3}H\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{(m+1)(m+2)}{2}\beta_2^m.$$

The index n in the recurrence formula Eq. 27 is a non-negative integer. In case the C's have negative subscripts, they are considered to be zero. The procedure for solving the problem is, first, to evaluate all C's in terms of C_0 using Eq. 27. Then, using the boundary condition at the entry where the axial stress σ_z is equal to the backpull σ_b and $\lambda = \sqrt{\beta_2}$, Eq. 26 becomes

$$\frac{\sigma_b}{\sigma_0} = \sum_{i=0,1,2\ldots} C_i \beta_i^{\frac{1}{2}}$$

and the value of C_0 can be determined. The stress distribution in the wire for a convex die of given profile is thus completely defined.

6. STRESS RELATIONS FOR BELL-SHAPE DIE

Now, consider the case of a conical die with a bell-shape profile as shown in Fig. 3*d*. If the die profile is given as

$$x = \frac{L}{2}\left[1 + \left(\frac{r - r_0}{r_1 - r_0}\right)^{\frac{1}{2}}\right], \tag{28}$$

where $r_0 = \frac{1}{2}(r_1 + r_2)$. Then

$$\varphi' = \frac{dx}{dr} = \frac{L}{6r_1\beta_0^{\frac{1}{2}}}(\beta_0 - \beta)^{-\frac{1}{2}} = \frac{M}{\gamma^2}, \tag{29}$$

where

$$M = \frac{L}{6r_1\beta_0^{\frac{1}{2}}} \quad \text{and} \quad \gamma = (\beta_0 - \beta)^{\frac{1}{2}}.$$

In a similar manner as in the previous sections, that is, placing the values of φ' from Eq. 29 into Eq. 11 and changing the variables, the differential equation of equilibrium becomes

$$\tfrac{1}{3}\left[-(1-\beta_0)M+\mu(1-\beta_0)\gamma^2-M\gamma^3+\mu\gamma^5\right]\frac{d}{d\gamma}\left(\frac{\sigma_z}{\sigma_0}\right)+2\mu(M^2+\gamma^4) \times \left(\frac{\sigma_z}{\sigma_0}\right)=2M(\mu M+\gamma^2)\left[1-2\left(\frac{k}{\sigma_0}\right)\ln(1-\beta)\right] \tag{30}$$

in which $\ln(1 - \beta)$ can be expanded into a power series in β, and then transformed into a power series in γ. It can be shown that the solution of Eq. 30 can be expressed as a power series

$$\left(\frac{\sigma_z}{\sigma_0}\right) = \sum_{i=0,1,2\ldots} E_i\gamma^i, \tag{31}$$

where the coefficients E can be determined from the following recurrence formula

$$\tfrac{1}{3}[-(1-\beta_0)MnE_n+6\mu M^2E_{n-1}+\mu(1-\beta_0)(n-2)E_{n-2} -M(n-3)E_{n-3}+\mu(n+1)E_{n-5}]-F_{n-1}=0 \quad (32)$$

and

$$F_0 = 2\mu M^2\left[1+2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{\beta_0^{m+1}}{m+1}\right]$$

$$F_1 = 0$$

$$F_2 = 2M\left[1+2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{\beta_0^{m+1}}{m+1}\right]$$

$$F_3 = -4\mu M^2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\beta_0^m$$

$$F_4 = 0$$

$$F_5 = -4M\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\beta_0^m$$

$$F_6 = 2\mu M^2\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}(m+1)\beta_0^m$$

$$F_7 = 0$$

$$F_8 = 2M\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}(m+1)\beta_0^m$$

$$F_9 = -\frac{4}{3}M^2\mu\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{(m+1)(m+2)}{2}\beta_0^m$$

$$F_{10} = 0$$

$$F_{11} = -\frac{4}{3}M\left(\frac{k}{\sigma_0}\right)\sum_{m=0,1,2\ldots}\frac{(m+1)(m+2)}{2}\beta_0^m.$$

The index n in the recurrence formula Eq. 32 is a non-negative integer. In case the E's have negative subscripts, they are considered to be zero. The coefficients in the power series solution Eq. 31 can be evaluated in the same manner as in the previous section. In this way, the stress distribution in wire drawing using a bell-shape die of given profile is completely defined.

7. NUMERICAL EXAMPLES AND DISCUSSION

Consider that a wire of initial radius $r_1 = 0.500$ in. is to be reduced to final radius $r_2 = 0.400$ in. by using the four different dies of straight, concave, convex and bell-shape profiles as given in previous sections. For all dies, the length L is assumed to be 1.000 in. The coefficient of friction μ between wire and die is assumed to be 0.100. The material is assumed to be plastic-rigid and has a stress-strain relation in simple tension as defined by

$$\sigma = \sigma_0 + k\epsilon'',$$

where $\sigma_0 = 100{,}000$ psi. and $k = 40{,}000$ psi. For all cases a backpull σ_b of 50,000 psi. is applied at the entry.

Using the methods given in previous sections, it is found that the solutions of the stress distribution in the drawn wire are

$$\left(\frac{\sigma_z}{\sigma_0}\right) = 1.2038 - 0.7038\left(\frac{r}{r_1}\right)^{2.0404} - 1.5842 \ln\left(\frac{r}{r_1}\right)$$

for the straight die;

$$\left(\frac{\sigma_z}{\sigma_0}\right) = 0.5 + 4.015\beta - 8.658\beta^2 + 28.09\beta^3 - 52.05\beta^4 + 111.8\beta^5 - 155.5\beta^6 + 276.6\beta^7$$

for the concave die;

$$\left(\frac{\sigma_z}{\sigma_0}\right) = 1.095 - 0.0935\lambda - 3.0007\lambda^2 - 0.7145\lambda^3 + 2.8954\lambda^4 + 0.9459\lambda^5 - 2.7688\lambda^6 - 1.1308\lambda^7 + 2.7595\lambda^8$$

for the convex die; and

$$\left(\frac{\sigma_z}{\sigma_0}\right) = 0.8311 - 0.1212\gamma - 0.0290\gamma^2 - 2.3524\gamma^3 - 0.1517\gamma^4 - 0.0496\gamma^5 - 2.4346\gamma^6 - 0.1138\gamma^7 - 0.6479\gamma^8 + 1.3661\gamma^9$$

for the bell-shape die. The draw stress σ_d needed at the exit is found to be

$\sigma_d = 1.1109\,\sigma_0$ for the straight die,
$\sigma_d = 1.1274\,\sigma_0$ for the concave die,
$\sigma_d = 1.0950\,\sigma_0$ for the convex die, and
$\sigma_d = 1.0839\,\sigma_0$ for the bell-shape die.

Comparing the foregoing draw stresses, the draw stress σ_d for the concave die is 1.5 per cent higher than for the straight die, that for the convex

die is 1.4 per cent less than for the straight die, and that for the bell-shape die is 2.4 per cent less than for the straight die.

Using Eq. 5, the pressure distribution in wire drawing along the die can be shown to be

$$p = \frac{\bar{\sigma} - \sigma_x}{1 - \frac{\mu}{\varphi'}}. \tag{33}$$

Thus the pressure distribution is defined by Eq. 33 provided that the stress distribution is known. By substituting the solutions of the stress distribution obtained for the four cases considered into Eq. 33, the pressure distributions along the dies have been determined and plotted in Fig. 4. It can be seen that the pressure distribution for the die of bell-

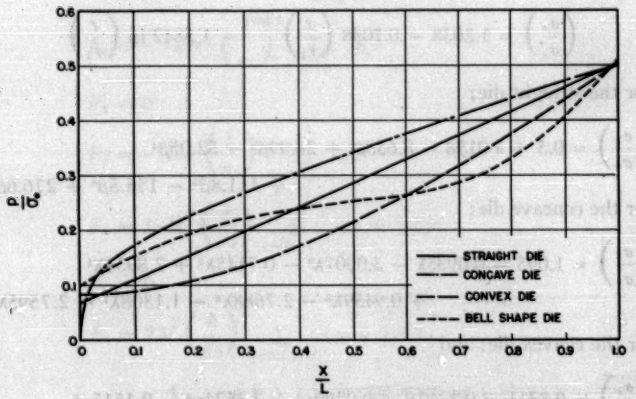


FIG. 4. Variations of pressure distribution along the die in wire drawing.

shape profile is the most uniformly distributed. This is a highly desirable feature in the functioning of dies in wire drawing.

Referring to Fig. 2, the frictional force on the die surface can be shown to be

$$\text{F.F.} = \mu p. \tag{34}$$

In other words, the distribution of frictional force is the same as the distribution of pressure p. For the four cases considered, the distribution of frictional force along the die can be computed by using Eqs. 33 and 34; a distribution curve similar to Fig. 4 can be plotted. Again, the die of bell-shape profile has the most uniformly distributed frictional

force along the die. Therefore, it can be expected that the wear of the die of bell-shape profile will be the most uniform one. This may be considered as a factor for better efficiency and longer service life of the die in wire drawing. Furthermore, it is of interest to note, as shown in Fig. 3, that the die profile has a prominent effect on the distribution of pressure and frictional force along the die, since in the four cases considered, the differences in die dimensions are very small.

8. CONCLUSION

In this paper, a general procedure was developed for the determination of stress in wire drawing using various die profiles. It was shown that the concept of total deformation in plastic flow can be used in the analysis of wire drawing. Cases of straight, concave, convex and bell-shape die profiles were studied and solutions of stress distribution were obtained. A numerical example was given, showing that the bell-shape die had the lowest draw stress and the most uniformly distributed pressure and frictional force. This is in agreement with the experimental results of Domes.

Acknowledgment

The analysis presented in this paper was prepared as part of a project on "Theoretical and Experimental Studies on the Mechanical Properties of Metals Under Triaxial Stresses" sponsored by the Office of Ordnance Research.

REFERENCES

(1) T. VON KARMAN, "Beitrag zur Theorie des Walzvorganges," *Z. angew. Math. Mechanik*, Vol. 5, pp. 139–142 (1925).
(2) G. SACHS, "Beitrag zur Theorie des Zeihvorganges," *Ibid.*, Vol. 7, pp. 235–236 (1927).
(3) E. A. DAVIS AND S. J. DOKOS, "Theory of Wire Drawing," *J. Appl. Mech.*, Vol. 11, pp. 193–198 (1944).
(4) R. HILL AND S. J. TUPPER, "A New Theory of the Plastic Deformation in Wire Drawing," *J. Iron and Steel Inst.*, Vol. 159, pp. 353–359 (1948).
(5) R. T. SHIELD, "Plastic Flow in a Converging Conical Channel," *J. Mech. Phys. Solids*, Vol. 3, pp. 246–258 (1955).
(6) W. LUEG, "Improving the Quality of Drawing Tools by Controlling Die Profile by Modern Measuring Methods," *Stahl und Eisen*, Vol. 71, pp. 157–170 (1951).
(7) J. G. WISTREICH, "Profile Measurement of Wire Drawing Dies: Recent German Developments," *Iron Coal Trades Rev.*, Vol. 163, pp. 965–968 (1951).
(8) J. HOLL, "Theoretical and Practical Determination of the Best Shape of Wire Drawing Dies," *Hutnik* (Prague), Vol. 3, pp. 130–134 (1933).
(9) V. DOMES, "Design and Measurement of Drawing Die Profiles," *Stahl und Eisen*, Vol. 71, pp. 1147–1148 (1951).
(10) C. W. MACGREGOR, "The True Stress-Strain Tension Test—Its Role in Modern Materials Testing," JOUR. FRANKLIN INST., Vol. 238, pp. 111–135 and 159–176 (1944).

Transatlantic TV?—The possibility of receiving television programs from the other side of the Atlantic has aroused great interest recently in view of the approach of the maximum phase of the 11-year cycle of sunspot activity. Already some success has been achieved by NBC who have, on occasions, been able to resolve recognizable pictures from the BBC (British Broadcasting Corporation) television transmitters at Crystal Palace, London, using a British receiver and a special aerial system at their receiving station at Riverhead, Long Island.

In London, the BBC has been keeping a watch on the U.S. television channels in order to screen for its viewers any pictures that might be received. Some signals have in fact been received intermittently, but it has not been possible as yet to resolve any kind of a picture.

The crux of the whole matter is the maximum usable frequency (m.u.f) which is rarely high enough to sustain propagation across the Atlantic at the frequencies used by television transmitters. However, around the sunspot maximum period there are occasions when the m.u.f. rises into the 40 mc. region and even, though much less often, into the 50 mc. region. At these times the lowest frequencies used for television in the U.K. (45 mc. vision, 41.5 mc. sound) may be receivable in the United States. The reception of reasonable pictures is a more difficult and chancy matter because of multi-path reception which causes ghosting.

The frequencies quoted above are shared by two television stations in the United Kingdom: the Crystal Palace station in London (e.r.p. 120 kW) which is likely to provide the predominant signal, and Divis in Northern Ireland (e.r.p. 12 kW). Both normally radiate the same program.

Reception of U.S. television transmissions in Britain is very much more difficult because the lowest frequencies used are those of Channel 2, 54–60 mc. Furthermore, these are shared by several stations, not necessarily radiating the same program, which makes the multi-path problem acute.

As the sunspot maximum approaches, m.u.f.'s have risen rapidly. In October 1956, the m.u.f. for the transatlantic circuit averaged 38.4 mc. at noon Greenwich Mean Time. In November this had risen to 44.6 mc. and in December to 45.4 mc. Long distance reception from the United States was good throughout December. Broadcasts on 26 mc. were received on 29 days and U.S. amateurs on 50 mc. were received on 11 days. Many other signals on frequencies between 30 and 50 mc. were received, and there was occasional reception on 56 mc.

Observations are continuing at the BBC's receiving station at Tatsfield, Surrey where an RCA receiver is installed ready for use if the reception of actual pictures seems likely. A second RCA receiver is installed at Alexandra Palace, in London, where there is direct connection with the BBC's television network.

QUANTIZATION OF THE RELATIVISTIC HARMONIC OSCILLATOR BY PERTURBATIVE METHODS WITH APPLICATION TO VAN DER WAALS FORCES

BY

R. H. PENFIELD [1] AND H. ZATZKIS [2]

ABSTRACT

The relativistic effects on the quantization of the harmonic oscillator are determined from a perturbation calculation using matrices obtained in the nonrelativistic case. One finds that the energy levels are no longer evenly spaced although the usual transition rules still hold.

When a system of two oscillators is considered and the relativistic modification together with radiation effects to second order on the energy of the system is determined, it is found that the higher order correction terms to van der Waals forces are both repulsive and show a dependence on separation distance of $1/R^5$ and $1/R^7$.

I. INTRODUCTION

The quantization of the relativistic harmonic oscillator can be carried out by a perturbation calculation using completely matrix procedures. The relativistic Hamiltonian is expanded in powers of c and the terms in c^{-2} are treated as a perturbation of the classical Hamiltonian. Since the matrices x and p for the classical oscillator are well known, the diagonal elements of the perturbation operator can be determined from those for x and p by the usual matrix multiplication rules. When this procedure is applied, the energy levels of the oscillator are no longer evenly spaced although the usual transition rules hold. Consequently, the spectrum consists of not just one line, but of infinitely many lines.

It is possible to construct the Hamiltonian for two relativistic oscillators separated by a large distance and to determine the relativistic effects to second order on the van der Waals forces between these oscillators. These relativistic correction terms are both repulsive and show a dependence on separation distance of $1/R^5$ and $1/R^7$.

II. HAMILTONIAN

As is well known, the relativistic Hamiltonian for the oscillator becomes

$$H = c(p^2 + m^2c^2)^{\frac{1}{2}} + V, \tag{1}$$

where $V = \frac{k}{2}x^2$ is the potential energy, m the rest mass, k the elastic

[1] Physics Department, Harpur College, Endicott, N. Y.

[2] Mathematics Department, Newark College of Engineering, Newark, N. J.

force constant, and $\omega = (k/m)^{\frac{1}{2}}$ the classical angular frequency. If the radical is expanded so as to include terms of order c^{-2} in H, one obtains

$$H = mc^2 + \frac{p^2}{2m} - \frac{p^4}{8m^3c^2} + \frac{k}{2}x^2. \tag{2}$$

It is convenient to introduce the notation

$$H = mc^2 + H_{el} + H', \tag{3}$$

where

$$H_{el} = \frac{p^2}{2m} + \frac{k}{2}x^2,$$

$$H' = -\frac{p^4}{8m^3c^2}.$$

H' is, of course, the perturbation term.

III. QUANTIZATION

Quantization is effected by considering the dynamical variables x and p as matrices which satisfy the equations of motion in Hamiltonian form as well as the quantum condition

$$xp - px = ih. \tag{4}$$

These three matrix equations determine the form of the matrices x and p up to an arbitrary phase factor. Since this procedure is familiar to everyone, only the results for x, p, and H_{el} are listed for present use.

$$\begin{aligned}
x_{n,n\pm1} &= (h/2m\omega)^{\frac{1}{2}} \begin{cases} (n+1)^{\frac{1}{2}}, \dots & n = 0,1,2,\dots \\ (n)^{\frac{1}{2}}, & n = 1,2,3,\dots \end{cases} \\
x_{n,m} &= 0 \quad m \neq n \pm 1 \\
p_{n,n\pm1} &= i(hm\omega/2)^{\frac{1}{2}} \begin{cases} -(n+1)^{\frac{1}{2}}, & n = 0,1,2,\dots \\ +n^{\frac{1}{2}}, & n = 1,2,3,\dots \end{cases} \\
p_{n,m} &= 0 \quad m \neq n \pm 1, \\
(H_{el})_{n,n} &= \hbar\omega(n + \tfrac{1}{2}), \qquad n = 0,1,2,\dots
\end{aligned} \tag{5}$$

The expression for p^2 is also useful and will also be listed.

$$\left.\begin{aligned}
p^2_{n,n} &= \tfrac{1}{2}hm\omega(2n+1), & n &= 0,1,2,\dots \\
p^2_{n+2,n} &= -\tfrac{1}{2}hm\omega[(n+2)(n+1)]^{\frac{1}{2}}, & n &= 0,1,2,\dots \\
p^2_{n-2,n} &= -\tfrac{1}{2}hm\omega[n(n-1)]^{\frac{1}{2}}, & n &= 2,3,4,\dots
\end{aligned}\right\} = \tfrac{1}{2}hm\omega M. \tag{6}$$

All other elements vanish. Because of the relationship

$$H' = -\frac{\hbar^2\omega^2}{32mc^2} M^2, \tag{7}$$

the elements of the M^2 matrix must be computed. The structure of the matrix is sufficiently simple that the calculation is quite short. One can write

$$M^2_{n,l} = M_{n,j}M_{j,l} = M_{n,n}M_{n,l} + M_{n,n-2}M_{n-2,l} + M_{n,n+2}M_{n+2,l}. \tag{8}$$

From this it follows that the only nonvanishing elements of $\mathbf{M}^2$ are $M^2_{n,n}$, $M^2_{n,n-2}$, $M^2_{n,n+2}$, $M^2_{n,n-4}$, and $M^2_{n,n+4}$. It is of course obvious that the matrices $\mathbf{M}$ and $\mathbf{M}^2$ are symmetric. Actually only the diagonal terms of $\mathbf{M}^2$ are needed here, but we shall list for future reference all elements of $\mathbf{M}^2$:

$$\begin{aligned}
M^2_{n,n} &= 3(2n^2 + 2n + 1), && n = 0,1,2,\ldots \\
M^2_{n,n+2} &= -2(2n + 3)[(n + 1)(n + 2)]^{\frac{1}{2}}, && n = 0,1,2,\ldots \\
M^2_{n,n-2} &= -2(2n - 1)[n(n - 1)]^{\frac{1}{2}}, && n = 2,3,4,\ldots \\
M^2_{n,n+4} &= [(n + 1)(n + 2)(n + 3)(n + 4)]^{\frac{1}{2}}, && n = 0,1,2,\ldots \\
M^2_{n,n-4} &= [n(n - 1)(n - 2)(n - 3)]^{\frac{1}{2}}, && n = 4,5,6,\ldots
\end{aligned} \tag{9}$$

Since the unperturbed Hamiltonian is nondegenerate, the energy eigenvalues are given by

$$\begin{aligned}
E_n &= mc^2 + (H_{el})_{n,n} + H'_{n,n}, \quad n = 0,1,2,\ldots \\
&= mc^2 + \hbar\omega(n + \tfrac{1}{2}) - \frac{3}{32}\frac{\hbar^2\omega^2}{mc^2}(2n^2 + 2n + 1).
\end{aligned} \tag{10}$$

One sees that the zero-point energy of the oscillator is given by the expression

$$E_0 = mc^2 + \tfrac{1}{2}\hbar\omega\left(1 - \frac{3}{16}\frac{\hbar\omega}{mc^2}\right), \tag{11}$$

up to terms of order c^{-3}. This is different from the classical result by the term $-\frac{3}{32}\frac{\hbar^2\omega^2}{mc^2}$.

One can also derive these results for E_n by introducing destruction and creation operators in the usual way:

$$\begin{aligned}
a &= (m\omega/2\hbar)^{\frac{1}{2}}x + i(1/2\hbar m\omega)^{\frac{1}{2}}p, \\
a^* &= (m\omega/2\hbar)^{\frac{1}{2}}x - i(1/2\hbar m\omega)^{\frac{1}{2}}p,
\end{aligned} \tag{12}$$

where a is the destruction operator and a^* the creation operator. The matrix elements for these operators,

$$\begin{aligned} a_{n-1,n} &= (n)^{\frac{1}{2}}, & n &= 0,1,2,\ldots \\ a_{m,n} &= 0 & m &\neq n-1, \\ a^*_{n+1,n} &= (n+1)^{\frac{1}{2}}, & n &= 0,1,2,\ldots \\ a^*_{m,n} &= 0 & m &\neq n-1, \end{aligned} \tag{13}$$

are well known and can be deduced from the matrix elements of x and p given in (5). The perturbation term becomes, upon introduction of the operators a and a^*,

$$-\frac{p^4}{8m^3c^3} = -\frac{1}{32}\frac{\hbar^2\omega^2}{mc^2}(a^*-a)(a^*-a)(a^*-a)(a^*-a), \tag{14}$$

where it is to be remembered that a and a^* do not commute. Only terms in which the creator operator appears as many times as the destruction operator give a nonvanishing result for the diagonal elements $(p^4)_{n,n}$. Using this fact, one obtains

$$\begin{aligned} [(a^*-a)^4]_{n,n} = (a^2a^{*2})_{n,n} + (a^{*2}a^2)_{n,n} + (aa^*aa^*)_{n,n} + (aa^*a^*a)_{n,n} \\ + (a^*aaa^*)_{n,n} + (a^*aa^*a)_{n,n}. \end{aligned} \tag{15}$$

If the commutation relation

$$aa^* - a^*a = 1 \tag{16}$$

is used, Eq. 15 can be simplified further to give

$$[(a^*-a)^4]_{n,n} = 6(a^2a^{*2})_{n,n} - 12(aa^*)_{n,n} + 3. \tag{17}$$

The matrix elements can be immediately evaluated to give

$$[(a^*-a)^4]_{n,n} = 3(2n^2+2n+1) \tag{18}$$

and, consequently, the expression for E_n is identical with the previous result. The use of creation and destruction operators is particularly convenient when one is considering the relativistic interaction of two harmonic oscillators.

IV. FREQUENCIES

The energy levels are no longer equally spaced as in the unperturbed system. On the other hand, the **X** matrix does not enter into the perturbation term (even if any higher power of **p** were included). Therefore, the original transition rules hold (since $|X_{ck}|^2$ is the probability of the $c \rightleftarrows k$ transition) and only transitions $k \rightleftarrows k+1$ are permissible.

There are infinitely many lines in the spectrum whose angular frequencies are given by

$$\omega_n = \frac{E_n - E_{n-1}}{\hbar} = \omega - \frac{3}{8}\frac{\hbar\omega^2}{mc^2}n, \quad n = 1,2,3,\ldots \tag{19}$$

after proper substitution has been made from Eq. 10. The first three lines are:

$$\begin{aligned}
\omega_1 &= \omega\left(1 - \frac{3}{8}\frac{\hbar\omega}{mc^2}\right), \\
\omega_2 &= \omega\left(1 - \frac{3}{4}\frac{\hbar\omega}{mc^2}\right), \\
\omega_3 &= \omega\left(1 - \frac{9}{8}\frac{\hbar\omega}{mc^2}\right).
\end{aligned} \tag{20}$$

V. RELATIVISTIC CORRECTIONS TO VAN DER WAALS FORCES

In order to predict the form of the van der Waals force between systems which are separated by large distances (R) compared with the interparticle distance in one given system, one carries on a perturbation calculation to obtain the energy of the interacting systems assuming that the distance between systems (R) is fixed. The energy will then be some function of the intersystem distance (R) and the gradient of the energy function gives the van der Waals forces between the system.

Here we wish to consider two oscillators as the systems and determine the relativistic corrections to the van der Waals forces, considering terms up to second order in (V/c). One must consider the vector as well as scalar potentials and take into account retardation effects by expanding the expressions for the fields in a series of powers of R/c.

The oscillators are imagined as vibrating electrical dipoles in which the positive charges e are attached to masses which are much greater than those associated with the negative charges $-e$. The negative charges vibrate about the positive charges in the direction of the line joining the two oscillators: their displacements will be denoted by x_1 and x_2.

The Lagrangian for this system can be written down at once:

$$\begin{aligned}
L = &- mc^2[1 - V_1^2/c^2]^{\frac{1}{2}} - mc^2[1 - V_2^2/c^2]^{\frac{1}{2}} - \tfrac{1}{2}kx_1^2 - \tfrac{1}{2}kx_2^2 \\
&- e\Phi_2(0,t) + e\Phi_2(x_1,t) - \frac{e}{c}A_2(x_1,t)V_1,
\end{aligned} \tag{21}$$

where

$$\Phi_2(0,t) = \int_2 \frac{\rho_{t-r/c}}{r}\,dV \tag{22}$$

and r is the distance from charges in oscillator No. 2 to the positive

charge in oscillator No. 1. $\Phi_2(x_1,t)$ has a similar meaning for the negative charge in oscillator No. 1. The vector potential $\mathbf{A}_2$ is given by the usual expression

$$\mathbf{A}_2(x_1,t) = \frac{1}{c}\int_2 \frac{j_{t-r/c}}{r}\,dV. \tag{23}$$

If one expands $\rho_{t-r/c}$ and $j_{t-r/c}$ in a series of powers of r/c, and performs the necessary integrations,[3] one obtains to terms of second order in Φ_2 and to first order in $\mathbf{A}_2$:

$$\begin{aligned}
\Phi_2(0,t) &= \frac{e}{R} - \frac{e}{R+x_2} - \frac{e}{2c^2}\frac{d^2x_2}{dt^2},\\
\Phi_2(x_1,t) &= \frac{e}{R-x_1} - \frac{e}{R+x_2-x_1} - \frac{e}{2c^2}\frac{d^2x_2}{dt^2},\\
\mathbf{A}_2(x,t) &= -\frac{e}{c}\frac{V_2}{R+x_2-x_1}.
\end{aligned} \tag{24}$$

After expanding these expressions in powers of x_1/R and substituting the resulting expressions for Φ_2 and $\mathbf{A}_2$ in the Lagrangian, one arrives at the following result for L:

$$\begin{aligned}
L = &-2mc^2 + \tfrac{1}{2}mV_1^2 + \tfrac{1}{2}mV_2^2 + \tfrac{1}{8}mV_1^4/c^2 + \tfrac{1}{8}mV_2^4/c^2\\
&- \tfrac{1}{2}kx_1^2 - \tfrac{1}{2}kx_2^2 + 2e^2\frac{x_1x_2}{R^3} + \frac{e^2}{c^2}V_1V_2W,
\end{aligned} \tag{25}$$

where

$$W = \frac{1}{R} - \frac{(x_2-x_1)}{R^2} + \frac{(x_2-x_1)^2}{R^3}.$$

If one introduces new coordinates y_1 and y_2 defined by

$$\begin{aligned}
x_1 &= \frac{1}{\sqrt{2}}(y_1+y_2),\\
x_2 &= \frac{1}{\sqrt{2}}(y_1-y_2),
\end{aligned} \tag{26}$$

and, consequently, new velocities u_1 and u_2 defined by

$$\begin{aligned}
V_1 &= \frac{1}{\sqrt{2}}(u_1+u_2),\\
V_2 &= \frac{1}{\sqrt{2}}(u_1-u_2),
\end{aligned} \tag{27}$$

[3] See, for instance, L. D. LANDAU AND E. M. LIFSHITZ, "Classical Theory of Fields," Cambridge, Addison-Wesley Press, 1951, pp. 181–182.

one obtains as the new Lagrangian

$$L = -2mc^2 + \tfrac{1}{2}mu_1^2 - \left(\tfrac{1}{2}k - \frac{e^2}{R^3}\right) y_1^2 + \tfrac{1}{2}mu_2^2$$
$$- \left(\tfrac{1}{2}k + \frac{e^2}{R^3}\right) y_2^2 + \frac{m}{16c^2}\,(u_1^4 + 6u_1^2u_2^2 + u_2^4)$$
$$+ \frac{e^2}{2c^2}\,(u_1^2 - u_2^2)\left(\frac{1}{R} + \sqrt{2}\,\frac{y_2}{R^2} + 2\,\frac{y_2^2}{R^3}\right). \quad (28)$$

VI. THE HAMILTONIAN

The Hamiltonian, minus the rest energy, correct to terms of second order in u^2/c^2, that results from the Lagrangian is

$$H = \frac{p_1^2}{2m} + \left(\tfrac{1}{2}k - \frac{e^2}{R^3}\right) y_1^2 + \frac{p_2^2}{2m} + \left(\tfrac{1}{2}k + \frac{e^2}{R^3}\right) y_2^2$$
$$- \frac{1}{16m^3c^2}\,(p_1^4 + 6p_1^2p_2^2 + p_2^4)$$
$$- \frac{e^2}{2c^2m^2}\,(p_1^2 - p_2^2)\left(\frac{1}{R} + \sqrt{2}\,\frac{y_2}{R^2} + \frac{2y_2^2}{R^3}\right). \quad (29)$$

In order to quantize the energy, one considers the Hamiltonian operator

$$H_{op} = H_{1op} + H_{2op} + H_{per.op.},$$
$$H_{1op} = \frac{p_1^2}{2m} + \left(\tfrac{1}{2}k - \frac{e^2}{R^3}\right) y_1^2,$$
$$H_{2op} = \frac{p_2^2}{2m} + \left(\tfrac{1}{2}k + \frac{e^2}{R^3}\right) y_2^2, \quad (30)$$
$$H_{per.op.} = -\frac{1}{16m^3c^2}\,(p_1^4 + 6p_1^2p_2^2 + p_2^4) - \frac{e^2}{2c^2m^2}\,p_1^2\left(\frac{1}{R} + \sqrt{2}\,\frac{y_2}{R^2} + \frac{2y_2^2}{R^3}\right) + \frac{e^2}{2c^2m^2}\left(\frac{p_2^2}{R} + \sqrt{2}\,\frac{p_2y_2p_2}{R^2} + \frac{p_2y_2p_2y_2 + y_2p_2y_2p_2}{R^3}\right).$$

The last expression has been written in a symmetrized way so that the Hamiltonian operator is Hermitian. One immediately sees that H_{1op} and H_{2op} are operators for two harmonic oscillators with different force constants, however. If one introduces the creation and destruction operator appropriate to each of these unperturbed oscillators,

$$
\begin{aligned}
p_1 &= -i(\hbar m\omega_1/2)^{\frac{1}{2}}(a_1^* - a_1),\\
y_1 &= (\hbar/2m\omega_1)^{\frac{1}{2}}(a_1^* + a_1),\\
p_2 &= -i(\hbar m\omega_2/2)^{\frac{1}{2}}(a_2^* - a_2),\\
y_2 &= (\hbar/2m\omega_2)^{\frac{1}{2}}(a_2^* + a_2),\\
\omega_1 &= \left(\frac{k}{m} - \frac{2e^2}{mR^3}\right)^{\frac{1}{2}},\\
\omega_2 &= \left(\frac{k}{m} + \frac{2e^2}{mR^3}\right)^{\frac{1}{2}},
\end{aligned}
\tag{31}
$$

the first-order perturbation correction to the lowest energy of the system of oscillators $(H_{\text{per.op.}})_{00,\,00}$ can be easily determined.

Only terms of the form $a_1a_1^*$, $a_2a_2^*$ or products of these expressions give a contribution to the matrix element $(H_{\text{per.op.}})_{00,\,00}$. The values of the matrix elements used in determining $(H_{\text{per.op.}})_{00,\,00}$ are given by the general expression

$$
(a_1^n a_1^{*m} a_2^s a_2^{*t})_{00,\,00} = \delta_{mn}\delta_{st} n!t! \tag{32}
$$

With the help of this formula, one readily arrives at the following expression for $(H_{\text{per.op.}})_{00,\,00}$:

$$
(H_{\text{per.op.}})_{00,\,00} = -\frac{3}{64}\frac{\hbar^2}{mc^2}(\omega_1 + \omega_2)^2 + \frac{he^2}{4mc^2R}(\omega_2 - \omega_1) - \frac{\hbar^2e^2}{4m^2c^2R^2}\left(\frac{\omega_1}{\omega_2} - 1\right). \tag{33}
$$

If one expands the square-root expressions for ω_1 and ω_2 and substitutes the results into the above expression, the following result is obtained:

$$
(H_{\text{per.op.}})_{00,\,00} = -\frac{3}{16}\frac{\hbar^2}{mc^2}\omega_0^2 + \frac{he^4}{2m^2c^2\omega_0}\frac{1}{R^4} + \frac{11}{16}\frac{\hbar^2e^4}{m^3c^2\omega_0^2}\frac{1}{R^6} + \text{terms of higher power in } \frac{1}{R}, \tag{34}
$$

where

$$
\omega_0 = (k/m)^{\frac{1}{2}}.
$$

One sees therefore after taking the derivative, that the relativistic correction terms to van der Waals forces are both repulsive and that a term in $1/R^5$ appears in addition to one in $1/R^7$.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS

PUNCHED CARD TRANSCRIBER FOR AUTOMATIC COMPUTERS

A punched card transcriber developed by the National Bureau of Standards makes possible more rapid feeding of data into an automatic computer. The device is designed to convert numbers and instructions recorded on punched cards into a binary serial code. In this form information is suitable for direct rapid input into the computer or temporary storage as a magnetic recording. The system is extremely fast—about 150 times faster than the present paper tape inscriber—and can handle up to 600 cards per min. Intended primarily for use with the Bureau's high speed electronic computer, SEAC,[1] the transcriber was developed by M. Stein of the Bureau's data-processing systems laboratory.

The transcriber can be utilized either as a means of preparing and feeding coded mathematical routines to the computer or for recording information on magnetic wire from cards which are already in existing files. In the preparation of routines, the use of punched cards offers an important advantage over perforated paper tapes. The cards provide a flexible means of modifying routines by simple insertions and removals. Previously, alterations in programming required remaking an entire punched paper tape.

When information appears on a punched card, it is in the form of one or two holes per column, representing numeric and alphabetic characters, respectively. The transcriber serially scans the 80 columns on each card with photoelectric cells and converts the data, one column at a time, into a 4- or 6-digit binary code at a rate ordinarily of 200 cards per min. This speed is dictated by the maximum pulse density allowed on the associated magnetic wire system. A simple mechanical conversion, however, can change the basic speed to 400 or 600 cards per min. The card reading mechanism is adapted from a commercial counting device.

In SEAC the hexadecimal counting system requires a 4-bit (binary digit) code accommodating ten decimal digits and six letters, A through F. The 6-bit feature is incorporated into the transcriber to provide for coding the remainder of the alphabet in special data processing problems. One to 6 SEAC words can be punched on each card for use with the 4-bit code. The 6-bit code permits the use of 8 words per card.

The circuitry is built up in two modes. One group is constructed with plug-in transformers and diode clusters similar to those in SEAC.

[1] "SEAC, the National Bureau of Standards Eastern Automatic Computer," *NBS Tech. News Bull.*, Vol. 34, p. 121 (1950).

The other group utilizes diode gated amplifier and delay line packages[2] identical with those in DYSEAC.[3]

The transcriber consists of two physically separate units. Most of the electronic circuitry is contained in the main chassis, while the photoelectric reading station is mounted on the counting device. It contains the photocells, light source, and necessary circuitry for converting the basic hole patterns into voltages in 14 different information channels. Twelve of the channels are for direct information transmittal and the remaining 2 are for control purposes. Pulses coming from the 12 photo cell information channels are fed into a gating matrix whose output is a 6-bit binary code. For hexadecimal operation two of the positions are muted to give a 4-bit output.

The remainder of the electronic circuitry utilizes the above signals to produce a parallel binary code which is stored one column at a time in a six-position staticizer. Each group of six pulses is then serialized and made available to the print circuit before the next card column is read.

The major portion of the circuitry is used to achieve the various complex timing functions which are inherent in a device of this type and to prevent misinterpretation of alphabetic data. One provision prevents false read-outs during the inter-card gap since at this time all the information channels are energized. Another provision compensates for card skew during the reading process, and hole misalignment in the card itself.

All timing circuits are keyed to a strobe pulse which is initiated by the leading edge of each punched column. This means that card flow need not be synchronous nor data flow continuous. The resultant output information is therefore available whenever data fields are being read, and there is no output at any other time.

Flexibility of operation is further enhanced by a self-inhibiting feature which allows entire fields of information to be ignored by the sensing circuits. Thus it is possible to punch descriptive information as well as computer data on the same card and only the desired data will be transcribed.

Prior to being put into operation, acceptance tests were performed on the transcriber in which ¼ million hexadecimal characters were converted without error into their binary equivalent. These figures, representing 20,000 SEAC words, were recorded under varying adverse conditions more severe than would be encountered in normal operation. To date, most of the information transcribed has been matrix data from existing card files.

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[2] "Circuitry packages for electronic computers," *Ibid.*, Vol. 37, p. 36 (1953).

[3] "DYSEAC—the New NBS Electronic Computer, *Ibid.*, Vol. 38, p. 134 (1954).

NOTE: For additional information on the NBS computer program see "Computer Development (SEAC and DYSEAC) at the National Bureau of Standards" (C 551). Available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Price, $2.00.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

March 20, 1957

The Stated Monthly Meeting of The Franklin Institute was held on March 20, 1957 in the Lecture Hall. Mr. S. Wyman Rolph, President, called the meeting to order at 8:15 P.M. with approximately 280 members and guests in attendance.

Mr. Rolph welcomed members of The Board of Directors of City Trusts of Philadelphia and their advisory committee who were present for the presentation of their John Scott Award.

The President announced that the minutes of the annual meeting had been printed in the February JOURNAL OF THE FRANKLIN INSTITUTE and the minutes of the February Stated Meeting had been printed in the March issue of the JOURNAL; there being no corrections, changes or additions, the minutes of both meetings were approved as published.

Mr. Rolph then introduced Mr. C. Raymond Kraus whose talk on "Experiments in Television over Telephone Cable Facilities" was well received.

After a brief question period the meeting was adjourned at 9:20 P.M. with a rising vote of thanks to Mr. Kraus.

C. M. WATERBURY,
Assistant Secretary

COMMITTEE ON SCIENCE AND THE ARTS

In looking over the records of the Committee on Science and the Arts representing its activities during the past year, an impressive fact presented itself, that is, three George A. Hoadley Certificates were awarded which represented a total of one hundred and twenty-five years of service to the Committee on a purely volunteer basis. The longest record of dedicated service was found to be that of Dr. G. H. Clamer who completed fifty-five years of faithful duties to the Committee, which is the longest period to date covered by a Hoadley Certificate. The other two Certificates called attention to the equally devoted and helpful services of Mr. John M. Weiss over an extended period of forty-five years, and Dr. James Stokley for a period of twenty-five years.

Such records of long association with a Committee that seeks to reward the most competent workers in several valued fields of human endeavor are inspirational not only for the length of service but for the spirit that generated them. No greater recognition or honor can accrue to this institution than that of seeking and finding the most qualified individual for a just and distinguished award. This labor of love is carried on by a group of seventy competent and renowned scientists and engineers who give their time freely and generously to see that this goal is accomplished.

(Abstract of Proceedings of Stated Meeting held Wednesday, March 13, 1957.)

HALL OF THE COMMITTEE,
Philadelphia, March 13, 1957.

MR. JOHN H. NEHER in the Chair.

The following reports were presented for final action:

No. 3295: Work of The Glenn L. Martin Company in Bonded Structures.

This report recommended the award of a John Price Wetherill Medal to The Glenn L. Martin Company, of Baltimore, Maryland, "In recognition of the intensive research, development and manufacture of bonded structures."

No. 3318: Brown Medal.

This report recommended the award of the Frank P. Brown Medal to Pier Luigi Nervi, of Rome, Italy, "In consideration of his outstanding contributions in pioneering new fields in reenforced concrete design, through the use of new processes of construction and new applications of stress analysis, resulting in broadening of architectural and engineering horizons."

D. S. FAHRNEY
Secretary to Committee

MEMBERSHIP

ACTIVE MEMBERS ELECTED BY THE BOARD OF MANAGERS
March 20, 1957

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Lester Collins '40
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Elmer Latshaw '32
P. J. Leaper '55
Thomas S. Lever '36
Henry Norris Russell '34
Harry C. Sundheim '36

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

SWANN, W. F. G.: Reality, Imagery and Fantasy

POWER, G. AND D. L. SCOTT-HUTTON: Slow Shearing Motion over a Hollow

SALZER, HERBERT E.: Numerical Integration of $y'' = \phi(x,y,y')$ Using Osculatory Interpolation

BEKKER, M. G.: Latest Developments in Off-the-Road Locomotion

GREENSPAN, DONALD: On a "Best" 9-Point Difference Equation Analogue of Laplace's Equation

KLEIN, BERTRAM: Shear Buckling of Simply Supported Rectangular Plates Tapered in Thickness

HODGE, P. G., JR. AND JOHN PAPA: Rotating Disks with No Plane of Symmetry

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 476 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and from 2 P.M. until 10 P.M. on Wednesdays.

RECENT ADDITIONS

ASTRONOMY

VAN ALLEN, JAMES ALFRED, ED. Scientific Uses of Earth Satellites. 1956.
WATTENBERG, DIEDRICH. Die Welt der Planeten. 1954.

BIBLIOGRAPHY

ANDERSON, LELAND I. Bibliography; Dr. Nikola Tesla (1856–1943). Ed. 2. 1956.
ASLIN, MARY S. Library Catalogue of Printed Books and Pamphlets on Agriculture, Published between 1471 and 1840. Ed. 2. 1940.
HERSHENSON, HERBERT M. Ultraviolet and Visible Absorption Spectra; Index for 1930–1954. 1956.

BIOGRAPHY

FRANKLIN, BENJAMIN. Autobiografia. n.d.

CHEMISTRY AND CHEMICAL TECHNOLOGY

BAHME, CHARLES W. Fire Protection for Chemicals. 1956.
BIFFEN, FRANK M. AND SEAMAN, WILLIAM. Modern Instruments in Chemical Analysis. 1956.
DAINTON, F. S. Chain Reactions. 1956.
FEIGL, FRITZ FRIEDRICH. Spot Tests in Organic Analysis. Ed. 5. 1956.
LEROY, ROYCE H. Problem Book for General Chemistry. 1951.
POTTER, EDMUND C. Electrochemistry. 1956.
SOCIETY OF CHEMICAL INDUSTRIES. Ion Exchange and its Applications. 1955.
WEISSBERGER, ARNOLD, ED. Separation and Purification. Ed. 2. 1956.

ELECTRICITY AND ELECTRICAL ENGINEERING

ARGUIMBAU, LAWRENCE BAKER AND STUART, R. D. Frequency Modulation. 1956.
BORGNIS, FRITZ E. AND PAPAS, CHARLES H. Randwertprobleme der Mikrowellenphysik. 1955.
CORCORAN, GEORGE FRANCIS AND REED, HENRY R. Introductory Electrical Engineering. 1957.
DUMMER, G. W. A. Fixed Capacitors. 1956.
FITZGERALD, ARTHUR EUGENE AND HIGGINBOTHAM, DAVID E. Basic Electrical Engineering. Ed. 2. 1957.
KUHN, W. E., ED. Arcs in Inert Atmospheres and Vacuum. 1956.
MOREL, ROGER. Contribution a l'Étude Rationnelle des Machines Électrostatiques. 1948.
ROST, RUDOLF. Kristalloden Technik. Ed. 2. 1956.

ENGINEERING

CAMPUS, F. AND MASSONNET, C. Recherches sur le Flambement de Colonnes en Acier A 37, à Profil en Double Té, Sollicitées Obliquement. n.d.
ELECTROCHEMICAL SOCIETY. CORROSION DIVISION. Stress Corrosion Cracking and Embrittlement. 1956.
JAEGER, JOHN CONRAD. Elasticity, Fracture and Flow. 1956.

GENERAL

BELLIN, JACQUES NIC. Description Geographique de la Guyane. 1763.
COLE, CHARLES C., JR. Encouraging Scientific Talent. 1956.

HISTORY

PANCIROLLUS, GUIDONIS. The History of Many Memorable Things Lost, Which Were in Use Among the Ancients. 1715.

MANUFACTURE

BARTON, HIRAM KENNETH. The Diecasting Process. 1956.

MATHEMATICS

BARROW, ISAACUM. Archimedis Opera. 1675.
BELOUSOW, S. L. Tables of Normalized Conjugated Legendre-Polynoms. 1956.
BUCK, R. CREIGHTON. Advanced Calculus. 1956.
CHEMICAL RUBBER COMPANY. C. R. C. Standard Mathematical Tables. Ed. 10. 1955.
KARAMZINA, L. N. Tables of Jacobi-Polynoms. 1954.
KNOPP, KONRAD. Theorie und Anwendung der Unendlichen Reihen. Ed. 4. 1947.
LEBEDEW, A. W. AND FEDOROWA, R. M. Reference Book on Mathematical Tables. 1956.
LIETZMANN, WALTER. Sonderlinge im Reich der Zahlen. Ed. 2. 1954.
MICHAEL, W. Ortskurvengeometrie in der Komplexen Zahlenebene. 1950.
SNEDDON, IAN N. Elements of Partial Differential Equations. 1957.
Tables of the Integral Exponential Function. 1954.
Tables of the Integral Sine and Cosine. 1954.
Tables of the Values of Bessel-Functions of Imaginary Arguments. 1950.

MECHANICAL ENGINEERING

BARWELL, F. T. Lubrication of Bearings. 1956.
DEGARMO, ERNEST PAUL. Materials and Processes in Manufacturing. 1957.
DONALDSON, CYRIL AND LECAIN, GEORGE H. Tool Design. Ed. 2. 1957.
HICKS, TYLER G. Pump Selection and Application. 1957.
POLJAK, S. M. AND SOROKIN, B. W. Neuzeitlichte Methoden der Spanlosen Kaltverformung. 1954.

METALLURGY

CHARLES, J. A.; CHATER, W. J. B. AND HARRISON, J. L. Oxygen in Iron and Steel Making. 1956.
POLUSHKIN, E. P. Defects and Failures of Metals. 1956.
RHINES, FREDERICK NIMS. Phase Diagrams in Metallurgy. 1956.

PHYSICS

BAKER, H. WRIGHT. Technology of Heat. 1956.
BEER, FERDINAND P. AND JOHNSTON, E. RUSSELL, JR. Mechanics for Engineers. 1957.
BRAUNBEK, WERNER. Forscher Erschüttern die Welt. 1956.
BRITISH JOURNAL OF APPLIED PHYSICS. The Physics of Nuclear Reactors. 1956.
CORCORAN, WILLIAM HARRISON; OPFELL, J. B. AND SAGE, B. H. Momentum Transfer in Fluids. 1956.
FREEMAN, IRA MAXIMILIAN. Modern Introductory Physics. Ed. 2. 1957.
ROCARD, YVES. Thermodynamique. 1952.
SEMAT, HENRY. Fundamentals of Physics. Ed. 3. 1957.
TOWNSEND, SIR JOHN. Electromagnetic Waves. 1951.
VICKERS, A. E. J., ED. Modern Methods of Microscopy. 1956.

RUBBER

McPHERSON, ARCHIBALD TURNER AND KLEMIN, ALEXANDER, ED. Engineering Uses of Rubber. 1956.

SCIENCE

DIJKSTERHUIS, EDUARD JAN. Die Mechanisierung des Weltbildes. 1956.
Some Milestones in the History of Science, to 1800. 1956.

STATISTICS

DIXON, WILFRID J. AND MASSEY, FRANK J. Introduction to Statistical Analysis. Ed. 2. 1957.
FISHER, SIR RONALD AYLMER. Statistical Methods and Scientific Inference. 1956.
FRASER, D. A. S. Nonparametric Methods in Statistics. 1957.

TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

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Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

COMPUTATION

"The nature of number is to be a standard of reference, of guidance, and of instruction in every doubt and difficulty. Were it not for number and its nature, nothing that exists would be clear to anybody, either in itself or in its relation to other things," wrote Philolaus, a Greek philosopher of the fifth century.

The Pythagorean School, to which he belonged, did a great deal to organize and improve the mathematical knowledge the Greeks had inherited from Egypt and Mesopotamia. What did they borrow and what did they create? The answer (and many others relating to mathematics) may be obtained at a glance from a new exhibit that has been installed as an introduction to the UNIVAC, that marvel of computation that has been added to the Institute.

Chronologically arranged, various dioramas, panels, and machines display the methods man has devised from earliest times to enable him to measure and to calculate. When civilization was in its simpler stages the most rudimentary methods sufficed for man's purpose but, as knowledge of the universe expanded and the coherent body of knowledge deduced from a number of principles, which we call science, was extended means had to be sought to simplify the growing complexity of measuring and calculating if men were to plan swiftly and accurately.

To save time in making his calculations, man had to make tools that would reduce his labor with pencil and paper. To the uninitiated these tools, slide rules, calculating machines, and such like, are frightfully complicated, but they employ simple basic principles.

The arithmetic of the scientist is the simple variety everyone used at school and still uses (when he cannot avoid it); addition, subtraction, multiplication, and division. Most of us can handle simple addition and subtraction fairly well, but are not happy when it becomes necessary to multiply six-figure or eight-figure numbers together. The task is now done accurately and quickly on a machine. But how did we arrive at the machine?

One method of abbreviating arithmetical work was to devise a record in an orderly manner of the results of frequently occurring combinations. These results, in the form of a table, were then available for subsequent use. Then computers began to think of machines that would do the work when the tables failed to meet their needs. The basic element of any arithmetical machine is a counting or adding unit.

For a while beads on strings or wires were employed, and still are used in the Orient.

John Napier, in 1617, invented numbering rods, which greatly facilitated the multiplication of numbers. These were later transferred to rotating cylinders which speeded their use. The first truly automatic operation was performed by the adding wheel invented by Blaise Pascal, which was confined to the operations of addition or subtraction. This adding wheel remained the basic element of practically all the arithmetical machines down to the present day. Some of them were very complicated mechanical structures, such as the Babbage and Scheutz "Difference Engines." The latter was actually used to compile mortality and other tables, but its application was limited. Nevertheless, a number of other machines were developed and perfected to the point where addition, subtraction, multiplication, and division were no longer time consuming problems. The operator inserted the numbers in the machine by means of a keyboard, pushed the proper control button, and read the results on dials.

Another development was the punched card as a means of writing and reading numbers, and of operating the controls of the machine. This left only the planning of the operation to be decided. No arithmetic had to be done, nor any individual control required. Basically, the punched card machine was an elaboration of the adding wheel.

Finally the electronic circuit was developed and applied as a computing mechanism. This device operates by means of vacuum tubes, similar to those in radio sets. There are no moving parts, so that these machines are capable of obtaining results at tremendous speed.

The Museum visitor has now the opportunity of seeing one of these machines, the UNIVAC, in actual use, and in order to understand its operation several operable exhibits are provided in the new display. In small space, the visitor can trace the main steps in the development of computation from earliest days and, without any mental effort, observe how machines have aided in reducing the labor of calculating.

This interesting display has been furnished with the co-operation of Remington Rand Division of The Sperry Rand Corporation, the makers of UNIVAC.

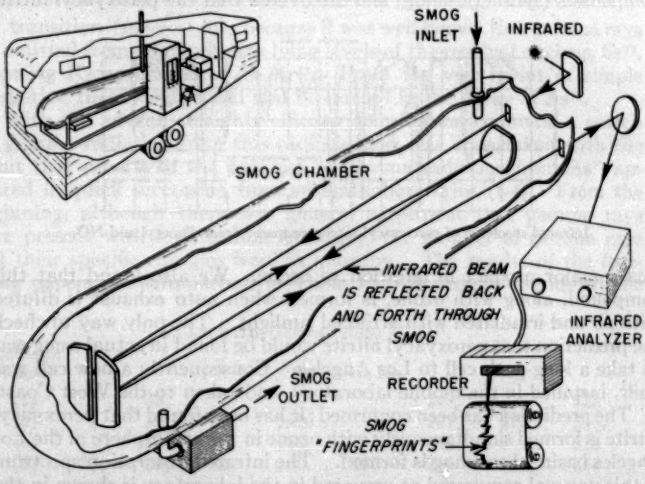
THE FRANKLIN INSTITUTE LABORATORIES
FOR RESEARCH AND DEVELOPMENT
NICOL H. SMITH, DIRECTOR

AIR POLLUTION LAB REPORTS FROM LOS ANGELES

BY

EDGAR R. STEPHENS*

One of the goals of research on the Los Angeles smog problem has been to find an explanation for the high concentrations of ozone during smog attacks. It has been shown in the laboratory[1] that high concentrations of ozone are produced by reactions between nitrogen dioxide and organic compounds in artificial sunlight. Franklin Institute research has demonstrated that the ozone concentration can build up to high levels because of the simultaneous formation of Compound X, a chemical identified as peroxyacyl nitrite.



Schematic of the ultra-long-path infrared absorption cell and spectrometer. This is a very versatile and powerful analytical tool, and provides the only method for detecting and identifying the unsuspected or unknown gaseous constituents of smog as found in Los Angeles —especially unstable chemical compounds like peroxyacyl nitrite.

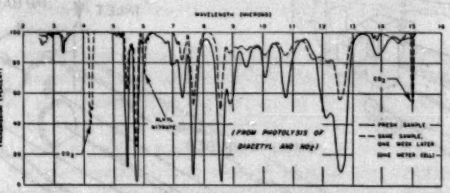
* Dr. Stephens, Leader of the Laboratories' Air Pollution Research Group, and Mr. Philip Hanst, Senior Research Chemist of that Group, have been stationed in Los Angeles since August, 1956, in charge of the Laboratories' Mobile Air Pollution Laboratory. The mobile lab was designed and built by the staff to extend research studies that began, and are still going on, in the Institute's Philadelphia laboratories. Both phases of this project are supported by the American Petroleum Institute.

[1] JOUR. FRANKLIN INST., Vol. 260, p. 140 (1955).

The role of peroxyacyl nitrite is as follows: Nitrogen dioxide, a man-made pollutant, decomposes in sunlight to form nitric oxide and atomic oxygen. The atomic oxygen combines with the normal oxygen of the atmosphere to form ozone. But the nitric oxide is removed from the scene by reacting with organic pollutants to form the peroxyacyl nitrite (Compound X). If the nitric oxide were *not* removed, it would react with the ozone; thus it would prohibit the ozone from building up to the high concentrations found in smog.

To complete the cycle, the peroxyacyl nitrite itself is decomposed slowly by sunlight to produce nitrogen dioxide, the substance which began the cycle. Thus the nitrogen dioxide is used over and over again to produce ozone.

Using an early model of the long-path infrared absorption cell in our Philadelphia lab, we studied nitrogen dioxide reactions with organic compounds (synthetic smog) and discovered that the peroxyacyl nitrite



Infrared spectrum of peroxyacyl nitrite prepared from diacetyl and NO_2.

was a major product in addition to ozone. We also found that this compound, along with ozone, is formed when auto exhaust is diluted with air and irradiated with artificial sunlight. The only way to check the prediction that peroxyacyl nitrite would be found in actual smog was to take a long-path cell to Los Angeles. Consequently a new cell was built, installed in the mobile laboratory, and taken to the West Coast.

The prediction has been confirmed; it has been found that peroxyacyl nitrite is formed simultaneously with ozone in the atmosphere of the Los Angeles basin when smog is formed. The infrared absorption spectrum of this unusual compound as prepared in the laboratory is shown in the illustration. It was identified in the atmosphere in Los Angeles by this characteristic absorption spectrum.

THE BARTOL RESEARCH FOUNDATION
W. F. G. SWANN, DIRECTOR

GAMMA RAYS OF As^{77}*

V. S. DUBEY† AND C. E. MANDEVILLE

ABSTRACT

The gamma-ray spectrum of As^{77} has been examined by scintillation counting methods. Previously reported radiations near 30 kev are shown to be bremsstrahlung, and by the coincidence method, a gamma ray of quantum energy 280 kev is found to be present.

INTRODUCTION

For many years, the radioactive element As^{77} was thought to be a pure beta-ray emitter. The absence of detectable gamma rays could be attributed only to insufficient efficiency of the detectors and to the operation of selection rules which favored an intense ground state beta-ray transition ($p_{\frac{3}{2}} \xrightarrow{\beta} p_{\frac{1}{2}}$), because it was well known that gamma rays are emitted from relatively low-lying levels of the residual nucleus, Se^{77}, following K-capture decay of Br^{77}. From the view point of simple energetics, these levels could also be excited in the decay of As^{77}.

With the advent of highly efficient scintillation counters, a search for gamma radiation from this radioelement was undertaken with the result that reports of the presence of gamma radiation from As^{77} appeared in quick succession from several laboratories (1-4). From the beginning, although there was general agreement that gamma rays were present with a detectable intensity, the number of gamma rays and their specific energies were in question. The results of the foregoing papers are summarized in Table I. All authors considered the

TABLE I.—*Gamma Rays of As^{77}.*

Reference Number	Energies in kev							
(1)		33,				245,		525
(2)		32,	87,	160,		247,	270,	520,
(3)			88,	155,		243,		528
(4)	23,	28,	86,	160,	186,	246,	283,	524

accuracy of their measurements to be a few kilovolts. Subsequent to the results summarized in Table I, a paper by Langevin (5) has appeared, reporting gamma rays at 86, 160, 245, and 525 kev. In her paper, Mme. Langevin considers in detail the previously reported soft radiations having energies lying between 23 and 33 kev, and describes a method of magnetic deflection of the nuclear beta rays whereby the

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† On leave of absence from Agra College, Agra, India.

apparent photopeak of a gamma ray or gamma rays in this energy region was suppressed. It was thus concluded (5) that the soft radiations were actually bremsstrahlung associated with the nuclear beta rays of As^{77} rather than gamma rays of a discrete energy.

Because of the inconsistent nature of the earlier reports, since a new interpretation had been lent the soft radiations, and because the presence of the previously reported (2) 270 kev radiation seemed not definitely established (5), the present writers have again investigated the quantum radiations of As^{77}.

THE MEASUREMENTS

The pulse-height spectrum of the gamma rays of As^{77} is shown in Fig. 1 where, in the region of 30 kev, only a smooth continuum is

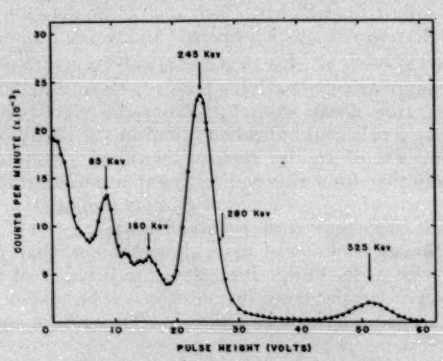


FIG. 1. Gamma-ray spectrum of As^{77} showing the presence of gamma rays at 85, 160, 245, and 525 kev.

visible. In obtaining this curve, the source was placed between two discs of carbon. The nuclear beta rays were absorbed in the carbon and thus few external bremsstrahlung were generated near the aluminum covered crystal. When the carbon discs were removed, a peak of counts resembling the photopeak of a 30 kev gamma ray became apparent. Thus, it can be concluded that, in agreement with the more recent measurements (5), the relatively broad peak previously reported (2,4) at about 30 kev must in actuality result from production of bremsstrahlung in the surroundings of the counter. The remaining continuum of low energy shown in Fig. 1 is thought to arise from Compton contributions of the gamma rays of higher energy from the K-x-rays of selenium and from phototube noise.

The data of Fig. 2*a* were obtained by fixing one channel of the

coincidence spectrometer at 280 kev and moving the other channel over the spectral region of lower energy. The results indicate that the 245 and 85 kev gamma rays are coincident with a 280 kev gamma ray. To obtain the data of Fig. 2*b*, one channel was fixed at 245 kev while the other was passed through the region of 280 kev to reveal a photopeak of

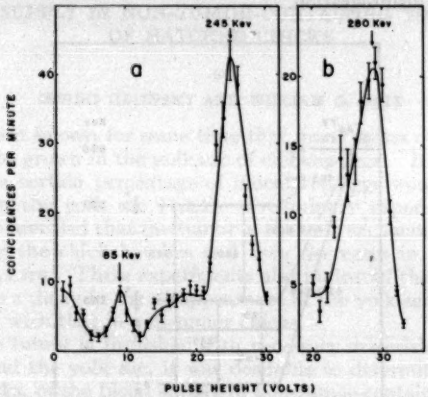


FIG. 2. Curve *a*, gamma rays of As^{77}, coincident with pulses corresponding to a quantum energy of 280 kev. Curve *b*, photopeak of a 280 kev gamma ray which is coincident to the 245 kev radiation.

coincidences arising from the presence of a gamma ray at 280 kev. From the measurements of Fig. 2, it may be concluded that a gamma ray at 280 kev is indeed emitted in the disintegration of As^{77}.

The present measurements and those previously cited (1-5) may be combined to give confirmation to the disintegration scheme of Fig. 3.

Zn^{69} AND Pd^{109}

Since scintillation counting methods had proven so successful in revealing gamma rays to be emitted in the decay of As^{77}, it was decided to examine some other elements which appear to be pure beta-ray emitters, having allowed beta-ray transitions.

One such case is the 52-min. Zn^{69}, decaying by beta emission to Ga^{69} according to the orbital changes $p_{\frac{1}{2}} \rightarrow p_{\frac{1}{2}}$ ($\Delta I = 1$, No !). The transition energy is 0.9 Mev. No gamma rays were detected in the decay of this 52-min. activity. The 440-kev gamma ray of Zn^{69m}, the 13.8-hr. parent element, was noted as previously reported (6).

Pd^{109} decays by a single beta transition of maximum energy 950 kev to a 40-second metastable state of Ag^{109} at 87 kev. However, by in-

elastic proton and alpha-particle scattering (7) additional levels in Ag^{109} have been located at excitation energies of 300 and 400 kev. An attempt was made to detect gamma rays of energies 300 and 400 kev in the decay of Pd^{109}, but no gamma rays were observed. From the conditions of the experiment, it was estimated that any other energetically possible unconverted gamma transition must have an intensity of less than 10^{-3} per disintegration.

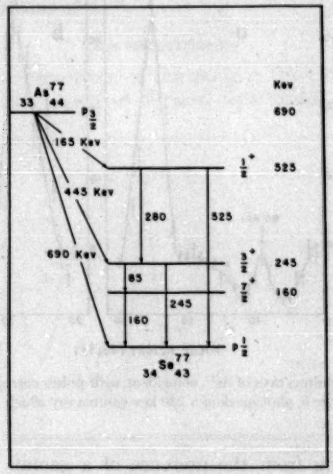


FIG. 3. Disintegration scheme of As^{77}.

REFERENCES

(1) REYNOLDS, LEDDICOTTE AND MAHLMAN, *Phys. Rev.*, Vol. 91, p. 333 (1953).
(2) SARAF, VARMA AND MANDEVILLE, *Bull. Am. Phys. Soc.*, Vol. 28, No. 4, p. 12 (1953); *Phys. Rev.*, Vol. 91, p. 1216 (1953).
(3) F. RASETTI AND E. C. BOOTH, *Phys. Rev.*, Vol. 91, p. 1192 (1953).
(4) BUNKER, PRESTWOOD AND STARNER, *Phys. Rev.*, Vol. 91, p. 1021 (1953).
(5) H. LANGEVIN, *J. Phys. et l. Rad.*, Vol. 16, p. 238 (1955).
(6) LEBLANK, CORK AND BURSON, *Phys. Rev.*, Vol. 97, p. 750 (1955).
(7) N. P. HEYDENBURG AND G. M. TEMMER, *Phys. Rev.*, Vol. 95, p. 861 (1954); T. HUUS AND A. LUNDÉN, *Phil Mag.*, Vol. 45, p. 966 (1954); FAGG, WOLIKI, BONDELID, DUNNING AND SNYDER, *Phys. Rev.*, Vol. 98, p. 1538 (1955).

THE BIOCHEMICAL RESEARCH FOUNDATION
ELLICE McDONALD, FOUNDER
WILLIAM G. BATT, DIRECTOR

BLOOD SUPPLY IN NON-TUMOR-CONTAINING YOLK SACS OF HATCHED CHICKS

BY
IRVING GALINSKY AND WILLIAM G. BATT

It had been known for some time that many types of heterologous tumors can be grown in the yolk sac of chicken eggs. It had also been shown that a certain percentage of inoculated eggs would hatch with the tumor in the yolk sac (1,2,3). Preliminary experiments by the authors have revealed that the tumor in the yolk sac increases in size for a while after the chick hatches and then decreases in size until the tumor disappears. These experiments also indicated that the yolk-sac tumors cause a delay in the disappearance of the yolk-sac blood supply as compared with that in non-tumor chicks.

Since the tumor is furnished with necessary materials by the blood supply around the yolk sac, it was desirable to determine the fate, in hatched chicks, of the blood supply of non-tumor-containing yolk sacs. For this purpose, paraffin was injected into yolk sacs of a number of eggs, to determine whether a solid mass of non-viable material would have any effect in delaying the disappearance of the yolk-sac blood supply as compared with that in non-treated eggs.

METHODS AND MATERIALS

Fertile, White Leghorn chicken eggs were used throughout these experiments. The eggs were divided into two groups. In the first group the eggs were allowed to hatch without any sort of treatment. In the second group 1.0 cc. of paraffin was injected into the yolk sac on the eighth day of incubation. The hatched chicks were sacrificed and the yolk sacs examined periodically. A total of 191 hatched chicks from non-treated eggs, and 127 hatched chicks from paraffin-injected eggs were examined.

OBSERVATIONS AND DISCUSSION

The 1.0-cc. paraffin, which is about the equivalent in size to 1.5-gm. tumor, was found to offer no mechanical obstruction and did not prevent the yolk sac from being taken into the abdominal cavity prior to hatching, a process which normally occurs during this period.

Generally, in non-treated chicks, the yolk material was gradually

absorbed and the yolk sac diminished in size until at about the tenth day after hatching, the yolk sac had completely disappeared or remained as a small yellow dot on the yolk stalk. After the 17th day the yolk sac was completely or almost completely absorbed in about 80 per cent of the chicks. In the remaining chicks where the yolk sac persisted long after it would normally have been absorbed, it was found that the yolk material had hardened into a solid mass in the yolk sac. However, most of the yolk sacs were almost completely absorbed before the yolk material hardened. In Table I it can be seen that there always seems

TABLE I.—*The Yolk Sac and Its Blood Supply in Chicks from Non-Treated Eggs.*

Days after Hatching	No. of Chicks	Yolk Sac Absorption, %				Yolk Sac Blood Supply, %		
		Complete	Almost Complete	Partial	Very Little	None	Fair	Good to Excellent
1–16	9	0.0	55.6	11.1	33.3	0.0	100.0	0.0
17–32	140	30.7	47.9	14.3	7.1	23.6	23.6	22.1
33–48	40	52.5	30.0	17.5	0.0	25.0	7.5	15.0

to be a certain percentage of the unabsorbed yolk sacs that maintain a good blood supply.

A comparison of the paraffin-injected chicks (Table II) with the non-

TABLE II.—*The Yolk Sac and Its Blood Supply in Chicks from Paraffin-Injected Eggs.*

Days after Hatching	No. of Chicks	Yolk Sac Absorption, %				Yolk Sac Blood Supply, %		
		Complete	Almost Complete	Partial	Very Little	None	Fair	Good to Excellent
1–16	16	0.0	0.0	0.0	100.0	12.5	6.3	81.2
17–32	14	14.3	14.3	7.1	64.0	14.3	28.6	21.4
33–48	33	36.4	3.0	0.0	60.6	18.2	27.3	18.2
49–64	17	52.9	0.0	0.0	47.1	0.0	0.0	47.1
65–80	18	55.6	11.1	5.6	27.7	11.1	0.0	33.3
81–125	21	23.8	23.8	4.7	47.7	19.0	19.0	38.1
126–139	—	—	—	—	—	—	—	—
140–160	13	30.8	15.4	0.0	53.8	23.1	23.1	23.1

treated chicks shows that the early presence of a solid greatly delayed the absorption of the yolk sac. In the paraffin-injected chicks the yolk material was generally absorbed until the yolk sac was tight around the paraffin. In those cases where the yolk sac disappeared, the absorption began at the part opposite the region of attachment to the yolk stalk. The delay in yolk-sac absorption appears to have allowed portions of the yolk sac to fuse with various tissues present in or around the abdominal cavity. This generally resulted in the development of a blood supply originating from the fused tissue and spreading over the yolk sac. If the yolk stalk became detached later, as happened in many cases, the yolk sac may still have had a good blood system supplied by the tissue to which it was fused.

CONCLUSIONS

The disappearance of the yolk-sac blood supply was delayed by the presence of a solid in the yolk sac. If this solid was present at time of hatching, it delayed the absorption process in a greater percentage of chicks than if the solid occurred in the yolk sac sometime after hatching.

The delay in the disappearance of the yolk-sac blood supply caused by a solid, indicated that such a delay caused by a yolk-sac tumor would be due mainly to its mass and not to any active metabolic demands.

Since a good blood supply still persisted as long as 5 months after hatching in some of the yolk sacs which contained solids, it seems likely that factors other than a limiting blood supply may be responsible for the disappearance of the tumor in the yolk sac.

REFERENCES

(1) D. R. TAYLOR, M. MCAFEE AND A. TAYLOR, *Cancer Research*, **3**, 542 (1943).
(2) J. T. KING, Z. B. BALL AND E. C. MENEFEE, *Proc. Soc. Exp. Biol. & Med.*, **57**, 3 (1944).
(3) C. P. DAGG, D. A. KARNOFSKY AND J. RODDY, *Cancer Research*, **16**, 589 (1956).

BOOK REVIEWS

PROGRESS IN NUCLEAR ENERGY, SERIES VII: MEDICAL SCIENCES (VOL. 1), edited by J. C. Bugher, J. Coursaget, and J. F. Loutit. 165 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc.; London, Pergamon Press, Ltd.; 1956. Price, $6.00.

"Profitable is that toil through
which so many sick have lived."
Latin proverb

As every scientist knows, science is international. In regard to his specialty, a scientist in pursuit of knowledge cares little about national boundaries. This is more likely to be true concerning medical applications of scientific knowledge where an effort (and desire) to help the sick of any nation is the ultimate goal. But even in the field of nuclear energy in medical science, certain war-time restrictions existed until the meeting at Geneva in August, 1955, of the International Conference for the Peaceful Uses of Atomic Energy. This meeting resulted in the pooling of the world's latest scientific knowledge in regard to the medical applications of nuclear energy and of making this information available to all through this book.

The volume begins with two forewords: the first by R. S. Stone and the second by Sir E. R. Carling. In them the stage is eloquently set and the reader gets a glimpse of the subject matter that is to follow in great detail. Although but seven chapters are listed in the table of contents, several contain additional sections written by other scientists not listed in the table. Adding to the high standards of the volume is an Editorial Advisory Group and Board consisting of 38 scientists and representing many countries.

The first chapter reviews the status of radioactive isotope techniques in medical diagnosis. Considered in detail are the methods of physical measurement and uses of isotopes in dilution techniques regarding investigations of blood volume, circulation and the red cell life span. Also described are the techniques in the detection and localization of tumors and the assessment of the functional state of many organs and tissues of the body.

The following chapter discusses the diagnosis and investigation of disease with radioactive isotopes mainly in regard to metabolism of the body as follows: water, electrolyte and intermediary metabolism, bones and teeth, uric acid and gout, lipids, metabolism of nucleic acid and carbohydrate, and of muscle and thyroid function. The radioisotope tracer method, which has been fruitful in further understanding the mechanisms and disease processes of erythropoiesis and iron metabolism, is considered. Although some problems are cited and left unsolved, much fundamental knowledge is brought to light. It is of interest to note that in a majority of patients afflicted with neoplastic disease, the survival time of the labelled red cells was as short as 25–85 days in contrast to the normal 120 day life span, although the fundamental reason why this is so remains unanswered. Dealt with also is the utilization of nuclear energy in the study of vitamin B_{12} deficiency, antibodies and diseases ranging from those caused by the influenza virus to protozoan and metazoan parasites.

In the next chapter concerned with nuclear radiations for radiotherapy with external sources, this reviewer is impressed with the section contributed by A. V. Kozlova of the Ministry of Health, U. S. S. R. Set forth are the extensively documented and advanced use in Russia of isotopes in the treatment of many kinds of malignant tumors and the striking results obtained. It is revealed among other things that, in the Soviet Union, the administration of radioactive cobalt to a large number of patients with malignant tumors from many parts of the body produced results which are not inferior to those when using natural radioactive substances. As

an example, when 450 patients with eye-lid skin tumor were treated at the Kharkov Institute, recovery was 94 per cent with no complications.

Chapter 4, which is written by investigators from several countries, considers the use of radioactive isotopes in haematologic therapy; medical applications of some radioactive isotopes; problems of radiotherapeutics; therapy of neoplastic diseases by means of radioactive suspensions; the utilization of colloidal chromic radiophosphate in the treatment of malignant tumors; and an accurate method for the treatment of hyperthyroidism with I^{131}.

With the discovery of X-rays, little or no safeguards were taken because none were thought necessary. However, within one month after Röntgen discovered his X-rays, an experimenter observed a dermatitis of his hands after working with X-radiation. Soon after many other radiation-induced changes appeared in man and experimental animals and a need became apparent to consider safeguards against the radiation. Because ionizing radiations are additive and their effects on cells generally deleterious, there has emerged—especially recently—a greater appreciation and respect for even slight exposure to the radiations. The older term, "tolerance dose," is no longer acceptable and we have now the concept of "maximum permissible dose." It is a fact that long continued, low intensity irradiation can produce genetic and body changes in organisms. In man it may require 15 or more years of a delay before the irradiation effects appear. In the following two chapters, which have been written by distinguished representatives of the U. S. A., U. S. S. R., Canada, the United Kingdom, Japan and international agencies, there is presented the world's latest knowledge in regard to principles and standards of radiation safety, codes of practice of different countries; legal aspects pertaining to radiation personnel; methods of production of harmful effects of reactor and chemical processing plant operation and hazards in the mining and processing of natural uranium and a summary of the reactor operating experience in Canada, the United Kingdom and the U. S. A.

The final chapter is a thorough review of the whole subject of dosimetry pertaining mainly to the determination of tissue dose in terms of the rad—the international unit of absorbed dose.

This outstanding volume will be read with profit and frequently consulted by those working in the field of radiobiology—especially individuals engaged in the medical application of nuclear energy in the treatment of the sick in all nations of the world. Like the good genie of Mohammedan mythology, the atom of this book plays the peaceful role for the good of mankind.

RALPH WICHTERMAN
Temple University

SCIENCE IN THE FEDERAL GOVERNMENT, by A. Hunter Dupree. 460 pages, 6 × 9¼ in. Cambridge, Harvard University Press, 1957. Price, $7.50.

Why should the government support science? One reason is that the government needs the new results the scientists obtain to assist it in the discharge of its responsibilities. Another thing is that the government needs to have available a body of experts it can call upon, from time to time, to furnish answers to scientific questions. Also, the government has felt the need in the past to stimulate industry by example as well as by precept, although it should be added in this connection, the subjects chosen for scientific inquiry should be of the nature to benefit industry in general rather than individual firms.

We are prone to believe government sponsored research has to do only with matters of defense, overlooking the responsibilities in ensuring work, health, food, and homes for all of us. In discharge of these civil responsibilities, scientific issues of all kinds are arising on which the administration requires guidance and information. But, in the main, the government is the provider, leaving to the prospective user the means of applying its findings.

Mr. Dupree, a teacher of history at the University of California, was inspired by the National Science Foundation and under the sponsorship of the American Academy of Arts and Sciences, to undertake the task of tracing the history of science in

the Federal Government. It was a formidable task for a historian to undertake since the field covers so many sciences, for science is not a new theme in Federal Government. Before the rise of the universities, the private foundations, and industrial laboratories, the fate of science rested almost exclusively with the government.

The author's concern is principally with the sciences of physics, chemistry, agriculture, and biology in all their specialities and varieties, with special emphasis on the institutional setting. He says: "As the history of the republic unrolled in the years down to 1940, scientific institutions within the government gradually solidified into a permanent establishment, the unsuccessful and abortive making their mark along with the rest. And the ideas behind them were quite as important as the actual organizations. Hence, this is a story of institutions and ideas." He might have added that it is, too, the story of the men behind the ideas, of living issues and passions.

Since Mr. Dupree has often been compelled to resort to primary sources of information his work, in many respects, has no counterpart in previous literature. In other well-travelled fields, such as the eras of the Civil War and World War I, he brings to bear a fresh vision and an original view-point which casts an illuminating insight upon his subject.

When the bombs were dropped on Hiroshima and Nagasaki, the nation became aware that science was a political, economic, and social force of the first magnitude. What the Federal Government had done to assist in making it so during the preceding one hundred and fifty years was little known. Mr. Dupree has been markedly successful in presenting a fully documented record of the achievement. What errors there are, are of a minor nature, such as the statement that A. D. Bache and Joseph Henry had their first meeting in London, overlooking their friendship as members of the American Philosophical Society and The Franklin Institute before either visited Europe.

T. COULSON
The Franklin Institute Museum

ATOMIC WEAPONS AND EAST-WEST RELATIONS, by P. M. S. Blackett. 107 pages, 5 × 7 in. New York, Cambridge University Press, 1956. Price, $2.00.

A curious phenomenon of this country's own making is the aspect of being a slave to the weapons we forged to bring freedom to all the peoples of the earth. Instead of freedom, it has shackled the free world so that the initiative in any warlike venture has been irrevocably surrendered to the East. Why? Let's have Prof. Blackett answer this. He compares the East and West as participants in a duel. "The one who strikes first wins; the one who fails to strike first is destroyed. In order not to be destroyed, the West would have to strike first—that is, the West would have to wage what would amount to preventative war. It is, however, almost an article of faith in the West that this cannot be done! Sentiment apart, a loose federation of states as N.A.T.O. is not likely to be good at this type of strategy, which needs strong nerves and quick decisions." Where then lies our salvation? Some of the answers are given and explored.

Thus through a small book of 100 pages run the arguments of Prof. Blackett. The author is a distinguished scientist and an incomparable physicist. In this deviation from science to political philosophy Prof. Blackett's uncanny knack of perceptual analysis reduces the entire picture of East-West relations to its proper perspective.

In the writing of this theme he has broken the problem up in three distinct sections and periods. The first period begins immediately after World War II in which we possessed complete atomic monopoly and the time when this country could have obtained anything it wanted through "atomic blackmail" but didn't. This was also the time when the West went all out to demobilize, for by 1948 our twelve million men under arms of World War II were reduced to 1.5 million.

Then came period II with the detonation of the first Russian atomic bomb at least five years before our military thought possible. This one event should have provided the clue as to the scale and magnitude of

Russian technology. The beginning of this period was marked by President Truman's order for the immediate and fullest commitment to the hydrogen bomb. This was the time when American superiority in atomic weapons was still manifest but this was the time that Russia made the supreme effort to catch up and perhaps overtake us in this weapons field. Here too it should be remembered that it was during this time that the Korean War was fought and even here, under the greatest provocation, nuclear weapons were not committed.

The third period began in 1953 when the Russians detonated a hydrogen bomb indicating that they have achieved or are achieving atomic parity. This third stage takes us to the present day.

What about wars? How will they be fought? Will we use nuclear weapons? How many H bombs or A bombs are necessary to cripple a country like the United States or like Great Britain? What are the strategic and tactical roles of these weapons? What type of army will be involved in the next war if one comes?

Against the backdrop of the three periods, Prof. Blackett tries to evolve answers which are so desperately needed today. The author quotes the foremost military men and heads of governments in his attempt to portray a complete picture. He analyzes their statements and shows that a significant portion of the anxiety the West experiences is due to erroneous military and political thinking.

Prof. Blackett shocks us by contradicting many long held opinions on which our thinking is predicated. If the learned scientist is right, and we hope he is, then "much of the West's fears were of its own imagining." In this we sincerely hope Prof. Blackett is right.

Atomic Weapons and East-West Relations is the briefest and yet most potent analysis ever offered of our relations with Russia. It is destined to have a tremendous impact on the political thought of the future and should be *required* reading for every student of World Affairs.

I. M. LEVITT
The Fels Planetarium

METALLURGY AND FUELS, PROGRESS IN NUCLEAR ENERGY SERIES V, edited by H. M. Finniston and J. P. Howe. 805 pages, illustrations, 6 × 9 in. New York, McGraw Hill Book Co., Inc.; London, Pergamon Press; 1956. Price, $21.00.

This massive volume is a tribute to the scientists and engineers who have devoted their time to classified work. It serves admirably to show the extended scope of the metallurgical work involved in the problems connected with the nuclear reactor. When we consider that most of the work discussed here was carried out over the past ten years, we wonder what the next ten years in nuclear energy will bring. Are we working on materials today that are as unfamiliar to the average metallurgist as were uranium, plutonium, thorium, etc. several years ago? If so, then a true revolution is taking place in metallurgy. The metallurgist, physicist and engineer are working closer than ever before and from this intimate association is evolving a new science of metals. The present text serves to illustrate the intensity of effort, the difficulties encountered, and the success attained on the problems associated with the metallurgy and fuels used for nuclear energy.

Over half of the book is devoted to the materials, uranium, thorium, beryllium, zirconium, plutonium, the rare earths, and ceramics. Ten authors contribute to the chapter on uranium. It is very thoroughly covered from its production and fabrication to its physical metallurgy. The section on the physical metallurgy is outstanding. It covers the properties, deformation mechanisms, orientation relationships, recrystallization and grain growth, thermal expansion, thermal cycling effects, irradiation effects, corrosion, and transformation kinetics. Twenty-seven binary phase diagrams are shown.

The section on beryllium and zirconium is well written but does not cover these metals nearly as thoroughly as do other recent textbooks.

It is evident from the chapter on plutonium that most of the information concerning this element has not been declassified.

In fact, it is quite interesting to note that the only phase diagrams of plutonium alloys that are shown are those published by the Russians.

About sixty pages are devoted to the subject of fuel elements. These papers discuss with a fair amount of detail the metallurgy and fabrication of the various elements used in reactors for research and power production.

About one-fifth of the book is devoted to the important and rapidly growing field of radiation damage. This section covers both the theoretical and practical aspects of the effects of irradiation and is an outstanding treatment of the subject.

The text ends with a chapter entitled "Solid State Physics." This deals primarily with neutron diffraction and the chemistry of the heavy element compounds.

The editors have done an excellent job on a fascinating subject. This text should prove to be an invaluable reference for the engineer, metallurgist, and physicist concerned with the materials problem in nuclear energy.

R. L. SMITH
Franklin Institute Laboratories

MOMENTUM TRANSFER IN FLUIDS, by W. H. Corcoran, J. B. Opfell, and B. H. Sage. 394 pages, diagrams, 6 × 9 in. New York, Academic Press, Inc., 1956. Price, $9.00.

The authors have compiled an exhaustive treatment of the highly specialized field of turbulence and boundary-layer analysis. The fundamentals of the subject matter are based essentially on previous presentations of Goldstein, Bakhmeteff, Karman, and others; the principal contribution of the authors is their collection and integration of the many significant studies which have been made during recent years.

The discussions of the physical characteristics of turbulence and boundary layers should serve as good background material for all students of fluid mechanics. The concepts of mixing length, eddy viscosity, and vorticity transport are presented and discussed in some detail. The mathematical treatments, including the statistical theory of turbulence, become rather advanced for the average graduate student; it is doubtful that the appendix labeled "An Introduction to Tensors" is adequate preparation for the derivations employing tensor analysis.

The chapter devoted to the derivation of the general equations of fluid motion is particularly valuable for its presentation of the Navier-Stokes equations in dimensionless form, as well as in cylindrical and spherical coordinates.

The authors are to be highly commended on their excellent format. Each chapter contains an introductory condensation of its contents, and features individual "Nomenclature" and "References" sections at its end.

This volume should be a welcome addition to the library of the fluid mechanics specialist, as well as serving as background reading for the non-specialist chemical or mechanical engineer.

DONALD E. NESTLER
Franklin Institute Laboratories

ADVANCES IN CANCER RESEARCH, Vol. IV, edited by Jesse P. Greenstein and Alexander Haddow. 416 pages, diagrams, 6 × 9 in. New York, Academic Press, Inc., 1956. Price, $10.00.

This volume maintains the high standards established in the preceding volumes. It contains 8 articles by 15 authors. The investigations reviewed are in several different branches of cancer research, which include chemotherapy, immunology, chemistry, and carcinogenesis. A survey of the contributors and their respective institutions shows the international scope of this volume of the series. Eight contributors are associated with organizations in the United States; four are from the University of Paris, France; two from hospitals in England; and one from the Netherlands Cancer Institute.

The first article, "Advances in Chemotherapy of Cancer in Man," is written by Doctor Sidney Farber and three other authors of Boston, Mass. The chemotherapy of acute leukemia is thoroughly reviewed. The discussion also covers the therapy of various types of cancer by selected chemical agents, such as antimetabolites, cytotoxic compounds, hormones, and antibiotics. Although several drugs have

been only temporarily successful in treatment of a few forms of cancer in man, these results offer some hope for the eventual cure of all neoplastic diseases. Consideration is also given to combination therapy, and to the development of resistance to drugs during therapy.

The second contribution is on "The Use of Myleran and Similar Agents in Chronic Leukemias" by Doctor A. G. Galton of the Royal Cancer Hospital, London, England. Some problems of clinical assessment in the chronic leukemias are discussed. Typical case reports are presented. Myleran has been found to be of some value in the management of chronic myeloid leukemia.

The following essay by Doctor Abraham Goldin of the National Cancer Institute, Bethesda, Maryland, is entitled, "The Employment of Methods of Inhibition Analysis in the Normal and Tumor-Bearing Mammalian Organism." He discusses the metabolite-antimetabolite relationships in the whole animal as well as various aspects of reversible and irreversible inhibition and of competitive and noncompetitive relationships. He describes the use of combinations of drugs in attempts to obtain synergistic effects.

"Some Recent Work on Tumor Immunity" is reviewed by Doctor P. A. Gorer of Guy's Hospital, London, England. Among the topics he discusses are: responses in animals to tumor grafts; methods for detection of antibodies; and means of lowering resistance to homografts.

Embryonic induction and differentiation in vertebrates are ably discussed by Doctor Clifford Grabstein of the National Institute, Bethesda, Maryland, in his article entitled, "Inductive Tissue Interaction in Development." Emphasis is placed on secondary inductions occurring in later embryonic development. The many complexities of inductive tissue interactions are reviewed. Carcinogenesis is compared to the known embryonic inductive processes.

Following is an article entitled, "Lipids in Cancer," by Doctors Frances L. Haven and W. R. Bloor of Rochester, New York. The lipid content and lipid metabolism of tumors are reviewed. Among the other aspects of lipids in tumors which are discussed is the role of lipids in carcinogenesis.

The next article is entitled, "The Relation Between Carcinogenic Activity and the Physical and Chemical Properties of Angular Benzacridines," by Doctor A. Lacassagne and three other authors of Paris, France. Some contributions of the disciplines of biology, chemistry, and physics to the understanding of carcinogenesis are reviewed. An appreciable amount of the research on benzacridine derivatives as carcinogenic agents was done by the authors. One of the tables in this article summarizes the results obtained on the carcinogenic effects of 78 benzacridine derivatives.

The last contribution is "The Hormonal Genesis of Mammary Cancer," by Doctor O. Muhlbock of The Netherlands Cancer Institute, Amsterdam, Holland. The hormonal aspects of the genesis of mammary carcinoma of the mouse are emphasized. However, other factors such as genetic constitution, environmental conditions, and the milk agents are given due consideration.

Each article is well documented with many references. Subject and author indices for the volume are included. This volume should be of considerable help not only to an investigator who is specializing in the branches of cancer research discussed, but also to one who desires to broaden his fields of interest.

W. D. YUSHOK
WILLIAM G. BATT
The Biochemical Research Foundation

RECENT ADVANCES IN SCIENCE, edited by Morris H. Shamos and George M. Murphy. 396 pages, illustrations, 6 × 9 in. New York, Interscience Publishers and New York University Press, 1956. Price, $7.50.

What's new in science? With the tremendous strides made in the sciences, even the professional is hard put keeping step with the most recent advances. For that reason, books such as *Recent Advances in Science* will be coming off the presses with increasing frequency. There is a definite need for this progress of science for both the professional and the layman.

In the spring of 1954 the First Symposium on Recent Advances in Science was held at

New York University. Invited to participate were recognized leaders in mathematics and physics. Names such as Rabi, Bethe, Shockley, Weisskopf, etc., insured authority to the topics they were asked to treat.

The book opens with a magnificent treatise on the methods of applied mathematics. Dr. Courant shows how mathematics is entering more and more into fields which heretofore were treated empirically. After the chapter on Operations Research, Dr. Rabi writes on Atomic Structure. Essentially it is a review of our knowledge of the atom from Democritus to the present day. This is a well written treatment of this subject by a ranking researcher in the field.

Dr. Townes explores the field of microwave spectroscopy and does an excellent job until he runs into the problem of timing the rotational period of the earth with an atomic clock. His explanation for the variation in the rotation of the earth is too speculative to have been included in a work of this type.

Bethe and Weisskopf write on "nuclear structure and transformations" and "elementary particles." Again these are masters of their fields and their chapters are models of exposition. There is some repetition, but it is not objectionable as it preserves the continuity of their individual pieces.

Leland Hayworth traces the development of particle accelerators from their infancy to the present and also gives us a glimpse of the shape of things to come. The alternating gradient synchrotron, a machine to yield energies of 50 Bev, is described as the atomic artillery of the future.

Neutron physics is discussed by Norman F. Ramsey and the section on transistor physics by Dr. Shockley is included. This has appeared in other publications in the past, but it is so skillfully written, so basic in its approach, that it "belongs" in a progress report of science.

A section on Ferromagnetism by R. M. Bozorth follows and then F. G. Brickwedde presents his chapter on Cryogenic Physics and Engineering. Dr. Condon writes the final piece on Physics and the Engineer.

Recent Advances in Science is a most difficult book to review. A brief review of such a variety of topics precludes justice being done to the whole or in part. As the title indicates, these pieces bring us up to date on the subjects outlined. Only the expert in a particular field can properly assess the conclusions or the indicated paths of future research. For a particular expert this book is still a wonderful addition to his source books.

This book should enjoy wide distribution and acceptance.

I. M. LEVITT
The Fels Planetarium

IRRIGATION ENGINEERING, VOL. II, by Ivan E. Houk. 531 pages, illustrations, 6 × 9 in. New York, John Wiley & Sons, Inc., 1956. Price, $14.00.

The material covered in this volume dealing with irrigation projects, conduits and structures is presented in exacting detail and with great clarity. This book should be invaluable as a reference for practicing engineers and for advanced courses in irrigation. It presents a wide range of material covering aspects of economy, legality, feasibility etc. of irrigation works. Most of the material deals with irrigation as practiced in the western states. However, the treatment is basic enough so that it has applications in the eastern states.

This is a work dealing primarily with the practical requirements concerning irrigation systems and includes a great deal of data on projects now in operation. The illustrations consisting of both photographs and drawings are excellent and add a great deal to the ease of understanding the written material. There are both a name index and a subject index which make it easy to locate material in the book.

Many basic formulas are presented along with hydraulic principles which should prove valuable in the design of structures required for the conveyance of water. Detailed information is given on existing irrigation projects from the planning stage to the maintenance and operation.

Cost of producing crops, land and water studies, the advisability of when and where to irrigate all receive complete coverage. The financial and engineering problems in

the construction of dams for impounding water are covered in several chapters.

It is expected that this book will be more widely used as a reference than as a text for undergraduate students. This can be expected since there are no formulas derived, sample problems worked out or typical practice problems included for classroom use.

Irrigation Engineering is highly recommended to anyone dealing with the design of irrigation works.

F. W. PEIKERT
The Pennsylvania State University

MATRIX CALCULUS, by E. Bodewig. 334 pages, 6 × 9 in. New York, Interscience Publishers, Inc., 1956. Price, $7.50.

The author's stated purpose in this book is a "systematic calculation with the true building blocks of a matrix, the rows and columns, avoiding the use of the individual elements." He achieves this purpose to a high degree making good use of an extensive new matrix notation.

A reader of the book should have some familiarity with linear algebra. Also for those who might like to read only portions of the book it will first be necessary to become completely familiar with the author's notation. Most of the notation and its properties are presented on pages 3 to 20.

The book is divided into four parts: Matrix Calculus, Linear Equations, Inversion and Eigen Problems. The first part serves as a review of matrix theory which includes a discussion of eigenvalues. The author introduces his notation during the review. Its effect on the conciseness of presentation is readily apparent.

The three remaining parts are presentations of the techniques for solving systems of linear equations, determining the inverse of a matrix and determining eigenvalues and eigenvectors. The presentation of each technique follows a definite pattern. The technique is described. Formulas used are derived with concise proofs for any theorems quoted. Wherever applicable a measure of the amount of work involved is given in terms of the number of multiplications. A discussion of the accuracy of the result is included along with a comparison with other techniques. Often the suitability of the technique to digital computers is also remarked upon. Finally examples are sometimes worked out.

In general the book is a presentation and evaluation of a large number of matrix calculation techniques. The use of a more complete notation than is commonly used, allows the presentation to be most concise. The effort required to first understand the notation is more than made up for in the short precise ways the matrix operations are described. The book should find wide use as a reference both for computational methods and for their derivations.

WILLIAM MCKAY
Franklin Institute Laboratories

CURRENTS, FIELDS, AND PARTICLES, by Francis Bitter. 599 pages, illustrations, 6 × 9 in. New York, John Wiley & Sons, Inc. and the Technology Press of MIT; London, Chapman & Hall, Ltd.; 1956. Price, $8.50.

This is a new book, admirably written and with an admirable aim. Whether such an aim can be achieved with the average student is, however, another matter. Professor Bitter's book is intended for the second year of a two-year physics course. The subject matter is electricity, magnetism, optics and atomic physics. In addition to the relatively high level of approach, a strong effort is made to integrate atomic and solid state physics concepts and problems into the section on electricity and magnetism. For example, Rutherford scattering is given a detailed treatment in the chapter on electrical properties of matter.

Aside from the strictly atomic physics section, this text resembles Frank's "Introduction to Electricity and Optics" in context and approach. Both of these books were written specifically for the selected, above-average students who go to MIT and who manage to get through the first year. Both texts, of course, can be used for junior or senior courses in electricity and magnetism at many schools.

The first eight chapters are on electricity and magnetism and these cover topics found in most electricity texts. There are important differences which make this book

modern in contrast to the older, classical treatments found in many other books. Electrical laws are related to atomic phenomena, conduction in gases, conduction in metals and semiconductors, the Hall effect, relativistic mass of electrons, the cyclotron, nuclear magnetic resonance, and so on. This book is modern in its choice of electrical subject matter as well. Nicely discussed are coaxial cables, waveguides, radiation, electronic circuits, and electrical resonance. There are two standard chapters on optics covering reflection, refraction, interference and diffraction. Then follow four chapters on atomic physics.

These four atomics chapters are: The Experimental Basis of Atomic Physics, Wave Mechanics, Atoms and Electrons, and Atomic Nuclei and Nuclear Radiations. Topics covered in the first chapter are X-rays and electron diffraction, photoelectricity, black body radiation, quantization of angular momentum, de Broglie waves, and the Stern-Gerlach experiment. The chapter on wave mechanics covers the wave function and its properties, the Schrödinger time independent equation, the uncertainty principle, and some simple applications. There is no question as to the excellent treatment, but it is questionable whether students will understand the concepts from the necessarily limited discussion. The "Atoms and Electrons" chapter is perhaps the least satisfactory chapter in the book. In it, Professor Bitter attempts to interpret the hydrogen atom in terms of the wave equation. However, the quantum numbers l and m are given to the student in a postulatory way without showing where they come from. The Bohr theory is then presented and given an exceedingly minor discussion. Generally, the order is reversed and the Bohr approach is given in a much fuller way. From a pedagogical point of view, it would seem that concepts would get across much better if the student knew Bohr theory before applying wave mechanics to the atom. Following the hydrogen atom, there are sections on the exclusion principle and the periodic table. X-ray spectra are given the standard approximate Moseley treatment. The final chapter on "Atomic Nuclei and Nuclear Radiations" is really a quick survey of elementary nuclear physics. It is quite unnecessary and unrelated to the main body of the book. Inasmuch as the author states that there is more in the book than can be covered and since he states that it is a new subject, it is not clear as to why it was included.

Professor Bitter states that his main objective is "the development of a series of abstract concepts which make it possible to see deeply into the nature of creation." On the whole, this new book is quite good in achieving the desired objective. There is some unevenness of treatment. Some subjects are treated rigorously and in a most modern way; others are given the traditional approximate discussion. Some modern terminology is used without proper amplifying definition. While most concepts are presented fully, that concerning the Poynting vector does not make sufficiently clear the limitations on S.

There is the usual large number of problems at the end of each chapter; answers to the even ones are given. Starred problems are of such a nature as to keep the brighter students from becoming bored. Vector notation and MKS units are used throughout the book. Each chapter closes with a brief summary of the chapter contents. Eight appendices (not listed in the table of contents) are included and cover damped simple harmonic motion, physical constants, conversion factors, list of the elements, periodic table, trigonometric functions and the Greek alphabet. Only a few obvious typographical errors were noted.

There is no question that this book represents a worthy effort but one wonders whether the second year physics students are capable of assimilating such a concentration of subject matter. It is to be hoped that laboratory instruction and lecture demonstrations would be on a par with the text and so enable the student to obtain a better understanding of these new and difficult concepts. Texts such as this one will become more valuable when the level of college preparatory training is raised.

LEONARD MULDAWER
Temple University

THE CHEMISTRY OF COORDINATION COMPOUNDS, edited by John C. Bailar, Jr. ACS Monograph 131. 834 pages, diagrams, 6×9 in. New York, Reinhold Publishing Corp., 1956. Price, $18.50.

A coordination compound can be described as being formed from any atom or ion which can accept a share in a pair of electrons and any atom or ion which can furnish a pair of electrons. This definition most aptly gives some concept of the enormity of the field that the editor has attempted to present in this one volume. Fortunately he has wisely chosen to provide some of the more basic concepts underlying the formation of coordination compounds rather than attempting to merely produce a cookbook of instructions on how to prepare and use chemical complexes. The book itself consists of twenty three chapters covering subjects that can be divided into five rather general topics:

(*A*) Survey of coordination compounds and the historical development of coordination theory, (*B*) Isomersion and stereochemistry of complexes, (*C*) Chemical reactions or processes and chemical compounds involving coordination compounds, (*D*) Use of physical methods to study coordination compounds and the application of complexes in electrodeposition and analytical chemistry, and (*E*) Use of coordination compounds and theories of formation in the study of natural products, dyes and pigments, and as applied to water softening.

It would be impossible to select any chapter or chapters over the others as being especially outstanding from the standpoint of technical content and all of them are provocative and make the reader want to seek further into the subject matter presented. Perhaps the reason for this effect is best understood from the comment by Professor Bailar in the Preface to the book —"We have attempted to present ideas which are fundamental and stimulating and applications which are both illustrative and useful." It is the opinion of the reviewer that the book certainly achieves this purpose. The book does not pretend to cover the chemistry of coordination compounds completely—each chapter is thoroughly annotated with the most current and up-to-date references which are of inestimable value to the reader who requires more detailed information on specific subjects.

The technical competence of the various contributed chapters of this volume is uniformly excellent in quality. However, there were three chapters that provided more and better information on the specific subject than the reviewer has been able to find in any other text currently available. The subjects covered in these chapters were: (*a*) olation (formation of complexes through hydroxyl groups), (*b*) polyacids (self-polymerized acids), and (*c*) the formation of complexes with olefin molecules.

With respect to recommendations for this book it seems indeed superfluous to say that it would obviously be a valuable addition to the chemist's bookshelf. More accurately, chemists are faced in their everyday work with an increasing need for knowledge of the formation, use, and theories of coordination compounds regardless of the fields of specialization. Hence this volume should be graduated from the position of a valuable tool of the chemist to an absolute necessity in his technical library.

DONALD H. RUSSELL
Franklin Institute Laboratories

RADIO TELEMETRY, by Myron H. Nichols and Lawrence L. Rauch. Second edition, 461 pages, illustrations, 6×9 in. New York, John Wiley & Sons, Inc., 1956. Price, $12.00.

The authors have both been actively engaged in the design and development of radio telemetry systems, especially those pioneering efforts carried out at Princeton. As with many other fields, which grew rapidly but still within the bounds of military security, few papers have been published on the many aspects of the field. Here for the first time is a book which presents both some basic theory and a cross section of current practice, including some original experience of the authors.

The book is divided into four parts, each of which may be read separately: methods; foundations; techniques; and appendices. Following a short introduction, the general

principles of telemetering are discussed, with emphasis on the systems point of view. Environmental and inherent errors are discussed, as are the various modulation and multiplexing schemes which are in use today. The second part is quite short, being devoted primarily to mathematical representations of the linear and non-linear processes by which telemetering may be described. Details of modern equipment and major components, with descriptions of specific systems, form the basis of the third part.

Throughout the book the authors never lose sight of the fact that telemetering systems must be precise and require definitive ways for making comparisons of systems. Such can be made in terms of minimum required signal strength, cross talk, susceptibility to environmental errors and information efficiency.

There is a wealth of material in the book, yet it is difficult to read. One reason for this may be that in order to keep the book to reasonable size, detailed explanations had to be kept to a minimum. Several minor typographical errors exist, but a careful reader will spot these readily. The book is recommended highly for its subject content to all engineers who must engage in telemetering techniques—and this means most engineers.

S. CHARP
Franklin Institute Laboratories

PUBLICATIONS RECEIVED

The Editors wish to call attention to these new books, received in the JOURNAL office for review. Lack of space prevents publication of more than this listing.

INTRODUCTION TO STATISTICAL ANALYSIS, by Wilfrid J. Dixon and Frank J. Massey, Jr. Second edition, 488 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $6.00.

FUNDAMENTALS OF PHYSICS, by Henry Semat. Third edition, 914 pages, illustrations, 6 × 9 in. New York, Rinehart & Company, Inc., 1957. Price, $8.00. (Also available in two volumes: Vol. I, Mechanics, Heat, Wave Motion and Sound, 464 pages; Vol. II, Electricity and Magnetism, Light, Atomics and Nucleonics, 496 pages.)

MODERN INTRODUCTORY PHYSICS, by Ira M. Freeman. Second edition, 497 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $6.00.

BASIC ELECTRICAL ENGINEERING, by A. E. Fitzgerald and David E. Higginbotham. Second edition, 540 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $6.50.

TOOL DESIGN, by Cyril Donaldson and George H. LeCain. Second edition, 557 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $6.75.

AEROPLANES AND AERO-ENGINES. Fourth edition, 24 cutaway drawings reprinted from *The Aeroplane*, 8½ × 12 in. New York, Philosophical Library, 1956. Price, $6.00.

CURRENT TOPICS

New Solid-State Oscillator for Microwaves.—The first successful operation of a completely new solid-state device which will oscillate at microwave frequencies has been achieved at Bell Telephone Laboratories by Dr. Derrick Scovil, Dr. George Feher and Dr. Harold Seidel. The device, which might be called a spin oscillator, will also operate, in principle, as an amplifier.

One of the outstanding characteristics of the new device is that it is expected to have very low noise compared with conventional microwave devices. Thus, in theory, it could markedly extend the range of radio astronomy and could result in radically new long distance communication systems to carry television programs and telephone calls across the continent. The development represents the first successful application to a solid-state device of a relatively new principle, which has been called the "maser" principle, which stands for "microwave amplication by stimulated emission of radiation."

This device, which is still in an early research stage, is expected to have novel and useful characteristics. Because it operates with electron spins in a paramagnetic crystal, theory predicts that it should have very low inherent noise compared to ordinary electronic oscillators or amplifiers which depend on the motion of charged particles at high temperatures. Therefore, it may be possible to amplify extremely weak radio signals—signals which may be several hundred times weaker than those usable at present.

Potentialities appear to exist for useful and novel microwave devices operating in the centimeter and millimeter wave region, although these experiments on a solid-state device are still in a very early research stage. As an amplifier, it should be moderately broadband with a bandwidth of the order of 100 megacycles, and easily tuned since its frequency is proportional to the applied magnetic field.

Preliminary theoretical estimates indicate that a noise figure corresponding to thermal noise at perhaps 5 or 10 deg. K. should be attainable. This is hundreds of times better than is now available with conventional microwave circuitry and if realized in practice will open wide new vistas in the microwave field.

The basic operation of this particular type of solid state device can be explained roughly by assuming three different energy levels for the unpaired spinning electrons in a paramagnetic crystal lattice in a magnetic field. Normal electron spin states are such that the number in state 1 (lowest energy state) exceeds the number in state 2, which in turn exceeds the number in state 3. By irradiating with sufficient microwave power of the proper frequency, transitions from state 1 to state 3 take place until the populations of these two states are essentially equal (power saturation).

Under these conditions the population of state 2 can be made greater than that of state 1. If a small signal is applied at a frequency corresponding to the energy difference between these two, then stimulated radiative

transitions will occur, and power gain will be realized. In the experiment conducted at Bell Laboratories, the energizing frequency was 17,500 mc and the signal frequency (in this case a self-sustained oscillation) was 9,000 mc.

A number of conditions have to be established before operation such as that described above can take place. In the first place, a single crystal of a solid-state material having certain specific characteristics is necessary. A whole group of materials, known as "ionically bound paramagnetic salts," appear to be suitable. After a careful survey, gadolinium ethyl sulphate was selected, although it is recognized that other compounds might perform as well or better for specific applications. Secondly, this material has to be diluted with an isomorphous diamagnetic substance to separate the gadolinium atoms sufficiently to reduce electron spin interaction. Lanthanum ethyl sulphate was selected, and it makes up about 99 per cent of the finished crystal.

The crystal was mounted in a waveguide cavity having two resonant frequencies, one equal to the frequency of oscillation, and one the frequency of the energizing source. The sample occupied about 8 per cent of the cavity volume, and was located at the point of maximum magnetic field intensity.

Low temperature operation is used so that power saturation of the crystal takes place with a reasonable amount of energizing oscillator power and also to increase the population difference between the energy levels. The sample and cavity were immersed in liquid helium at reduced pressure which provides a temperature of 1.2° K.

To produce the necessary separation of the electron spin energy levels, a magnetic field is required. A value of 2800 oersteds was employed in the device built at Bell Laboratories. This magnetic field may be altered to change the electron spin energies and thus tune the frequency of the stimulated radiation. The field must be properly aligned with respect to the crystal, and can be provided either by a permanent magnet or an electromagnet.

Equipment employed at the Bell Laboratories in demonstrating the operation of this new solid state device included a waveguide cavity, with the crystal in place, immersed in liquid helium. This assembly was located in the field of a strong electromagnet. The 17,500 megacycle energizing oscillator signal was brought to the cavity through a rectangular waveguide, and the stimulated radiation of 9,000 megacycles was taken away by means of a strip guide mounted inside the rectangular waveguide. Measured power output was about 20 microwatts. Energizing oscillator power, which might be compared to "B +" power in a conventional amplifier or oscillator, was about 100 milliwatts to insure saturation of the crystal. Satisfactory operation can be attained with much less power.

Because of the very low noise factor which this device is expected to have, an improvement of several hundred times in sensitivity for a microwave receiver is theoretically possible.

By using the proper waveguide structure and by using an adequate amount of paramagnetic material, it is expected that sufficient gain can be achieved to realize the advantages of the low noise figure.

Although the experiment as carried out at Bell Laboratories produced oscillations at 9,000 mc., operation at both much lower and higher frequen-

cies is possible with proper choice of solid-state materials and operating conditions. Thus, the solid-state "maser" shows promise of being useful as a pre-amplifier in a wide variety of microwave applications.

Briefcase Conference Recorder.—Now, with the improved "WALKIE-RECORDALL," the miniature Conference Recorder-Transcriber, "on-the-spot" recordings may be made in or out of closed briefcase. The instrument is self-powered—no wires, no warm-up period, no exposed microphone—and operation is completely noiseless.

It picks up and records voices within a 60-ft. radius, screening interferences such as typing, coughing, air-conditioners, traffic etc. Designed especially for recording Conferences, Lectures, Interviews, Sales training, Reports, Investigation, Dictation, 2-way Telephone, etc., the instrument is made by Miles Reproducer Co., Inc., of New York City.

To adapt this Conference Recorder for dictating in noisy places, an optional built-in provision permits the exclusion of everything except the voice spoken or whispered close to the mike—indoors or outdoors, in the office, field, car, train, or plane—without any interference from noises such as near-by conversations, motors, engines, etc.

The "Recordall" operates from self-contained standard dry batteries costing only 1¢ per hour, and affords continuous recording up to 4 hours on each side of a non-flammable safety-film belt costing only 3¢ per hour. Recordings are permanent, non-magnetic and non-erasable, unaltered and indexed. Recording starts instantly as soon as voice is started and stops, automatically, within approximately 8 seconds after voice ceases. This eliminates supervision and the recording of silent periods.

An indexed groove-finder permits immediate and accurate location for playback or for adding subsequent recordings without rewinding. Subsequent recordings may be started accurately where the last recording ended, even after removing and replacing recording belt.

Magnesium Pellet Extrusion Process.—A new process which increases the strength of magnesium alloy extrusions as much as 40 per cent has been developed for the Air Force by the Air Research and Development Command (ARDC).

With the new process, the magnesium is extruded from 0.016-in. spherical pellets rather than from solid magnesium billets normally used. The pellets are blown into the extrusion container and bonded into structural shapes by the friction, temperature, and pressure of the extrusion process.

A large increase in comprehensive yield strength is made without sacrificing any of magnesium's desirable qualities. In addition, the new method eliminates the need for machining solid billets prior to extrusion. It does not require the separate compacting operation which is usual in powder metallurgy.

The Magnesium Department of the Dow Chemical Company, Midland, Mich., spent nine years developing the process under sponsorship of the Materials Laboratory at ARDC's Wright Air Development Center, Dayton, Ohio. Magnesium alloy extrusions made by this method are now in production.

Magnesium is widely used as a structural metal by the Air Force because of its lightness and high strength-to-weight ratio. The new strength-giving extrusion process will

allow considerable weight reductions in military aircraft.

Extrusion is a common method of shaping metal by pushing it through a small opening, somewhat similar to forcing toothpaste through the top of its tube.

Pellets are produced for the new extrusion process by melting the magnesium, then alloying it with zinc and zirconium for added strength—a step common in magnesium processing. The liquid magnesium is then piped into a large atomizer tank where it is poured onto a spinning disc.

The spinning disc hurls off small molten droplets of the magnesium by centrifugal force. The droplets cool as they fall through a natural gas atmosphere and are solid balls by the time they hit the bottom of the tank.

These solid magnesium spheres—called pellets—are then heated to about 600 degrees Fahrenheit and blown directly into the extrusion press. Finally, under the high temperatures created by the frictional heating in the extrusion process, the pellets are forced together as they pass through the press and are bonded into structural shapes.

The strength of magnesium extrusions is increased by the new process because the use of the small pellets permits the metal to achieve a fine grain structure in the finished section. Magnesium is strengthened when its grain size is reduced.

Compressive yield strength of an 11-in. I-beam extruded by the pellet process, for example, is increased from 30,000 to 42,000 psi. or 40 per cent. Compressive yield strength of a four-inch I beam is increased from 30,000 to 40,000 psi., or 33 per cent. These improvements are what make it possible to reduce military airplane weights.

NIXIE—Electronic Read-Out Tube.—The first mass-produced all-electronic "read-out" tube is now in volume production at Burroughs Corporation's Electronic Tube Division, Plainfield, N. J., the Company has announced. The tube, known as NIXIE, is described as a small, low-cost electron device which converts electronic signals directly to readable characters. It contains all the numeric digits, any one of which can be selected and displayed in a common viewing area. It can be triggered by Beam Switching Tubes or any suitable voltage source requiring approximately ¼ watt.

Applications for the NIXIE tube include computer read-out, industrial control, electronic instrumentation, military electronic control, and channel selectors.

Unusually good readability is said to result from design features which provide a wide viewing angle and sharply defined digit contours. Other advantages claimed for the NIXIE are compactness, and a rugged construction capable of meeting military requirements for shock, vibration, and temperature.

According to the manufacturer, the NIXIE uses a minimum of power, circuitry and components and is inexpensive to install and maintain. It is believed by Burroughs to be the simplest all-electronic method of performing the read-out function.

Closed TV Patrols Reactor.—A closed circuit television camera is being groomed by General Electric engineers at the Hanford atomic plant for the ticklish task of patrolling the rear face of an atomic reactor. Designed to move automatically along a monorail near the wall of the reactor, the camera will transmit a picture of reactor components to an operator

seated at a console behind thick radiation shielding.

Television already has been tried successfully in a Hanford building where the nuclear fuel plutonium is extracted from fissioned uranium, but this test marks the first attempt to use TV at a reactor site.

Use of the camera is expected to speed maintenance jobs by making it possible to pinpoint trouble spots before special work crews are sent into the area. The camera will move along the monorail, examining pipes for leaks, and observing fuel elements as they are removed during discharge operations. It will afford closer supervision of work details and will eliminate the present use of a cumbersome set of mirrors to see around the protective labyrinth which shields against radiation.

The camera is installed in a protective metal box where its lens peers out through a safety glass window. If moisture collects on the window, an automotive-type window wiper wipes it clear. A floodlight on each side of the camera box provides illumination.

Equipped with a pan and tilt mechanism, the TV camera can be turned or "tilted" simply by moving a switch at the control panel. By combining the features of a vertically-movable monorail with the pan and tilt apparatus, General Electric engineers have provided a means of gaining complete camera coverage of the entire face of the reactor.

The TV picture is transmitted through coaxial cables to the control room monitor where it is displayed on a monitor similar to a home-type TV receiver. The same picture is transmitted to a 21-inch viewer near the front face of the reactor to inform other workers of progress at the rear of the reactor.

The camera contains a vidicon tube, amplifiers, and optical lens with focusing system. The lens is focused remotely from the control point by an electrically driven focusing mechanism.

Its remote operation is considered its outstanding feature. With it, a thorough inspection of a reactor's rear face can be conducted, unhampered by the presence of radiation which would make it impossible for workers to remain in the area for more than a short time.

Color television is now used by crane operators at a Hanford chemical separations plant. High image brilliance on the TV screens and added depth perception afford easier operation of giant hooks in a highly radioactive area and where formerly periscopes were the only means whereby operators could observe their work.

High-Speed Ditchers.—Mobile ditching machines capable of digging 4-ft. deep trenches at rates exceeding 20 ft. a minute are undergoing tests at the Corps of Engineers' Research and Development Laboratories, Fort Belvoir, Va.

Manufactured by the Owen-Pewthers Company of College Station, Texas, and the Barber-Greene Company of Aurora, Ill., the rubber-tired units may prove extremely useful to the Army and the Civil Defense Administration in providing protection for personnel against flash burns or fragmentary bombs, and radioactive blast.

The Barber-Greene model, mounted on a special vehicle which is powered by a 154-h.p. diesel engine, can dig the trench at the rate of 28 ft. a minute. It has 21 buckets with interchangeable insert-type teeth.

Mounted on a standard truck, the Owen-Pewthers' unit is capable of digging at the rate of 24 ft. a minute.

Its hydraulically operated boom can be placed into the digging position in less than a minute after arrival at a site.

The machine consists of 40 buckets which are equipped with interchangeable insert-type teeth, and features a side leveling mechanism that permits it to dig on side slopes up to 15 deg.

Both units have a maximum digging depth of 6 ft. and can excavate a foxhole in 30 sec. They can also be used for the rapid excavation of other types of field fortifications and utility trenches.

Tests are being held at the Engineer Proving Ground to determine their compliance with established military requirements for rubber-tired ditching machines.

Tubes for the Transatlantic Cable System.—The new transatlantic telephone cable system depends on the use of hundreds of specially designed very long life vacuum tubes housed in containers lying on the ocean bottom. Two main types of tubes are in operation. One, called the 6P12, is functioning in rigid repeater housings, and was developed at the British Post Office. The other, designed specifically for use in flexible repeaters for deep-water laying, was developed at Bell Telephone Laboratories, and has been assigned the designation 175HQ. The designs of these two tubes to meet the system objectives are quite different.

At Bell Laboratories the development of a tube for a transatlantic telephone cable was started in 1933. Conducive to long life, the tube was designed to operate at the lowest practical operating cathode temperature. The plate and screen voltages were reduced to the lowest values consistent with good circuit performance, and the current drain from the cathode was reduced to the lowest practical value. In addition, the spacings between electrodes were made as large as possible consistent with satisfactory electrical characteristics.

The operating cathode temperature is 670° C., which is in the neighborhood of 100° below that used in many radio and television receiver type tubes. The cathode current drain is only approximately 0.7 milliampere per square centimeter, whereas some of the newer commercial type tubes operate at 50 milliamperes per square centimeter. The spacing between control grid and cathode is 0.024 in., giving a transconductance of about 1,000 micromhos.

Some operating experience with the tube has been obtained in the Key West–Havana cable system which was laid in 1950. Here six repeaters, containing a total of 18 tubes, have been operating for approximately six and one half years without any perceptible aging effects to date.

Tubes which are essentially typical of those on the sea bottom across the Atlantic have been on life test for approximately 17 years with no failures in thermionic activity. Those which have failed because of mechanical defects have been carefully studied and changes in design have been introduced which have corrected the defects. There is reasonable probability that these tubes will operate without failure for at least 20 years.

The fabrication of the tubes for the Newfoundland to Scotland section of the cable system was carried out at Bell Laboratories. All tubes were aged for 5,000 hours (seven months), during which time various electrical tests were made to study the individual performance of each tube. In all approximately 500,000 bits of pertinent information were recorded. Complete records were kept on all materials used

in the tubes. Before acceptance for use, new materials, when practical, were made up in trial lots with accelerated tests to determine suitability.

The British Post Office tube follows the general design of tubes used in their earlier shallow-water systems. This tube has closely spaced electrodes and a high transconductance—6,700 micromhos. Because of the use of a rigid repeater housing which was developed originally for shallow-water use, the space available for the amplifier circuit is sufficiently liberal to allow the use of six tubes in each amplifier, arranged in two strings of three which operate essentially independently. A failure of one tube in one side of the amplifier will not in general seriously impair the operation of the other side of the amplifier, and continuity of service is thus provided.

It is of interest to note that the two groups working on the tubes on opposite sides of the Atlantic had no intimate knowledge of each other's work until after the tube designs had been well established. As a result of subsequent discussions, it was surprising and gratifying to find how similarly the two groups looked at the problems of reliability of tubes for submarine cables.

Styrex 767 in Full-Scale Production.—Full-scale commercial production of Styrex *767*, a Dow plastic material based on styrene and acrylonitrile, has been announced by The Dow Chemical Company, Midland, Mich.

Styrex, first introduced to Dow customers and the plastics industry on a limited scale in mid-1956, is being produced in a new plant at Dow's Midland Division, D. L. Gibb, sales manager of the company's Plastics Department, said.

According to Gibb, Styrex *767*, a rigid themoplastic which can be readily molded or extruded into various shapes and forms, is an improved styrene-acrylonitrile copolymer with an excellent balance of physical properties, high degree of toughness and heat resistance. It is resistant, he said, to acids, bases, salts, oils, waxes, soaps, food stains and many solvents, including gasoline and kerosene. Styrex *767* provides a high degree of clarity in transparent colors and can be produced in a broad range of opaque colors as well.

An extensive research and field evaluation program has shown it to be outstanding for such varied items as tumblers, rigid food containers, cutlery handles, dentures, bristles, refrigerator parts, aerosol nozzles and pencil barrels, Gibb reported.

New Electronic Data-Processing Computer.—A large-scale electronic computer specifically designed to help business management solve its problems scientifically has been announced by International Business Machines Corporation. The new system, the IBM *709*, is the latest addition to the company's 700-series of electronic data-processing machines. The *709* is the first equipment of its capacity that can work with equal facility on both commercial and scientific or engineering calculations.

The *709* systems will vary considerably as to the number of units used, but a typical system would lease for around $56,000 a month or sell for about $3,000,000.

L. H. LaMotte, IBM executive vice president and general manager of its Data Processing Division, said that the introduction of the *709* opens a new phase in the evolution of the electronic computer and its application in business and industry. He said, "Scientific management and operations

research are methods whereby the businessman makes use of the scientific approach in matters traditionally outside of the scope of science. They call for a merging of business and scientific principles. The new IBM 709 system does the same thing, electronically."

The new 709 data-processing system utilizes instructions unlike any of those found in present-day stored program computers. Developed to provide greater programming flexibility, they include conversion instructions which permit the machine to perform rapidly calculations on data prepared in number systems other than the 709's basic system of binary arithmetic. This means that all problem data can be kept in whatever form is most economical and desirable for the work at hand, rather than in a number system compatible to the computer.

The new 709 system introduces IBM's 729 Magnetic Tape Unit which features a data-processing innovation. The 729 automatically checks for accuracy information written on magnetic tape as it is being written—the first time this feature has been available in a data processing system. The unit signals when an error is detected, the tape writing operation may then be stopped, and the information rewritten.

Arithmetical operations are performed by the IBM 709 at amazingly high speeds. The new system can handle up to 42,000 additions or subtractions a second; multiplications or divisions are performed at speeds of up to 5,000 a second.

An important contributing factor to this extraordinary calculating speed is the 709's rapid access, high capacity magnetic core storage or "memory." Up to 32,768 "words" of problem or instruction data can be held in core storage, a "word" being equal to a ten decimal digit number. This means that the equivalent of over 327,000 decimal digits can be stored in the 709's magnetic core storage. Any "word" in core storage can be located and made ready for use in only 12 millionths of a second. The magnetic core storage unit's tremendous capacity fulfills the need for completely internal high-speed handling of voluminous problem data, reference tables, and lengthy programs.

Another aid to the 709's high-powered operation is the new IBM 766 Data Synchronizer which permits the system to read, write, and calculate simultaneously. Up to three data synchronizers can be included in a 709 computing system, each containing two channels for entering and taking out problem data. Eight tape units can be attached to each of these channels, making it possible to utilize up to 48 tape units. A card reader, card punch, and printer can be attached to one channel of each data synchronizer for nine additional input-output units and two magnetic drum storage units and an IBM 740 Cathode Ray Tube Recorder can be connected to the central processing unit, for a total of 60 input-output units that can be incorporated in a 709 system.

Any combination of six input-output units can be operating simultaneously, one for each of the six channels provided by the three 766 Data Synchronizers. For example, a tape and a card reader can be reading the problem while two tape units, a printer, and a card punch are writing out parts of the solution. While this information is being transmitted into or out of the system, the 709's high-speed arithmetic unit is completely free to calculate other phases of the problem.

All magnetic tapes produced by the new IBM 709 may be used with other IBM 700-series computers. Existing

programs for the IBM 704 can be run on the new 709 with variations in the input-output routine.

New Amplifier Klystron.—For use as the final amplifier of a high power microwave transmitter, a new klystron tube, the VA–806, has been introduced by Varian Associates, Palo Alto, Calif., manufacturers of klystrons and related microwave equipment. The VA–806 has performance characteristics that permit amplification of frequency, amplitude or phase modulated signals at power gains on the order of 50 db. It features a unique, all-ceramic and metal construction.

This new VA–806 provides 2,000 watts of continuous power in the 7125 to 8500 megacycle frequency range. It is a water cooled, four cavity cascade amplifier that is tunable ± 25 megacycles from the specified center frequency.

According to the manufacturer, the particular advantages of the new amplifier klystron include its long life, high gain, rugged integral cavities and low microphonics. The VA–806 features matched waveguide input and output and low FM and AM noise.

Electronic Data Transmission Between Government and Industry.—A roll of magnetic tape about the size of a dinner plate has replaced a 900-page report to speed the Social Security information of 30,000 General Electric Company employees from Schenectady to Baltimore.

This latest application of automation principles to accounting marks the beginning of a new era of data transmission between industry and the government, since this is the first application of the procedure.

According to Gerald L. Phillippe, General Electric comptroller, the potential savings of such an operation are tremendous to both the government and the company. General Electric employs more than 280,000 persons throughout the country and eventually it is expected that Social Security information for most of them will be forwarded by the tape method.

In addition to the saving in time and materials for the preparation of the Social Security records, there is also a huge saving in storage space required to keep the records.

The tape, which is approximately 2,400 ft. long and weighs about two pounds, carried the quarterly Social Security report for most of the General Electric employees in the Schenectady area. Until tape was used, it was necessary to prepare more than 900 typewritten pages, each containing 30 to 40 names, four times a year to supply the quarterly figures which the government requires for Social Security.

Under the new procedure, data are fed into International Business Machines computers for compiling General Electric payrolls and at the same time the special tape is run off for the Social Security Administration's records. The newly-written tape is taken from the IBM 702 computer and put into a plastic bag which is sealed to keep the humidity constant during transmission to Baltimore, headquarters for Social Security Administration.

Running a payroll through the IBM machines for the General Electric employees in Schenectady requires approximately 28 hours, or about three and a half seconds per employee. The Social Security tape is run off simultaneously. Eventually, the time may be chopped down to two seconds or less per employee.

The master payroll data is initially written on magnetic tape from punch

cards. Data fed into the computer for storage on the tape includes names, addresses, department designations and various other payroll statistics pertaining to employees.

When payrolls are prepared, the current information added to that previously fed into the computer is used to compute gross pay, deduct for such items as savings bonds, pension contributions, taxes, union dues and scores of other items, including Social Security. The net amount or take-home pay is computed and a check is prepared for the employee, all by machine. For employees who have requested General Electric to deposit their checks in the banks, a special form is employed to show the employee his earnings, deductions and the amount deposited in the bank of his choice.

An indication of the flexibility of the payroll computing operation can be gained from the fact that it prepares bank deposits for General Electric employees using 500 different banks; calculates 12 different taxes, deducts multiples of any combination of 90 types of deductions and computes payrolls using 33 different bases. In addition to paying General Electric employees in the Schenectady area, checks are prepared for some employees stationed throughout the country on assignment from departments with headquarters here.

Acceptance by Social Security of General Electric's proposal to use tape instead of paper eliminates the preparation of the 900-odd sheets and the necessity for handling them in Baltimore. The computer is capable of running 75 in. of tape per second with approximately 200 characters of information per inch.

When the 10½-in. roll of tape is received in Baltimore it is put through a computer there and the earnings reflected in the data are credited to the Social Security accounts of the individuals listed on the tape from General Electric. Previously, it was necessary to punch cards for each individual name listed on the 900-odd sheets sent from Schenectady and then to put the cards through computing machines. The tape method eliminates the punching step in Baltimore, and cuts down on storage space.

The computer used in preparing the payrolls and for other accounting work is sheltered like a gilded lily in 2,400 sq. ft. of space on the fourth floor of one of the company's office buildings here. The temperature is a vacationist's paradise—never less than 70 or more than 80 deg.—and the relative humidity is between 40 and 60. Three General Electric 10-ton unit air conditioners supply the filtered air to keep the computer in the proper atmospheric environment.